Presentazione

Questo è un "e-Proceedings" (electronic Proceedings), relativo ai lavori della *Giornata della FIMA*, la Federazione Italiana di Matematica Applicata, svoltasi il 27 Ottobre 2017, nell'aula Marconi della Sede del CNR, a Roma.

Si tratta delle slides delle presentazioni di 10 esperti, dei quali 2 proposti da ciascuna delle 5 associazioni scientifiche che costituiscono al momento attuale la FIMA, e cioè **AILA** (Associazione Italiana di Logica e sue Applicazioni), **AIRO** (Associazione Italiana di Ricerca Operativa), **AMASES** (Associazione per la Matematica Applicata alle Scienze Economiche e Sociali), **AIMETA** (Associazione Italiana di Meccanica Teorica e Applicata) e **SIMAI** (Società Italiana di Matematica Applicata e Industriale).

Nel corso della giornata di lavoro, i 5 Presidenti (o loro delgati) hanno firmato, a titolo di Convenzione, uno Statuto che ufficializza la Federazione.

I 10 conferenzieri sono stati scelti, a titolo di Comitato Scientifico, dai 5 Presidenti delle associazioni suddette, rispettivamente Antonio Di Nola (AILA), Daniele Vigo (AIRO), Bruno Viscolani (AMASES), Paolo Luchini (AIMETA) e Luca Formaggia (SIMAI), oltre al Presidente uscente dell'AILA, Carlo Toffalori, a Sandra Carillo (facente le funzioni del Presidente in carica dell'AIMETA), e dal sottoscritto.

Renato Spigler

Roma, 3 Novembre 2017

FEDERAZIONE ITALIANA DI MATEMATICA APPLICATA

STATUTO

Art. 1 (Denominazione, sede e durata)

Il nome della Federazione è FEDERAZIONE ITALIANA DI MATEMATICA APPLICATA (FIMA)

La Federazione riunisce Associazioni scientifiche italiane inerenti la Matematica Applicata.

La Federazione è una organizzazione scientifica senza fini di lucro e la sua durata è illimitata.

Essa ha la sede sociale in Roma presso l’Istituto per le Applicazioni del Calcolo (IAC) del CNR.

Art. 2 (Scopi)

La Federazione ha come scopi:

- riunire, promuovere ed incentivare lo scambio scientifico, tecnico ed applicativo nel campo della Matematica Applicata;

- favorire lo scambio di informazioni e le relazioni fra i vari Enti che si occupano di Matematica Applicata, promuovere la stipula di convenzioni con tali Enti e la partecipazione a organismi internazionali;

- promuovere congressi, seminari e workshop;

- favorire la ricerca scientifica e la costituzione di gruppi di ricerca;

- incoraggiare e stimolare la diffusione e l'insegnamento della Matematica Applicata;

- promuovere specifiche pubblicazioni di carattere scientifico e divulgativo della materia.

Art 3 (Categorie di Associati, autonomia e modalità di adesione)

Gli Associati della Federazione sono singole Associazioni che condividono gli scopi di cui al precedente articolo e che hanno sottoscritto l’atto costitutivo o che hanno successivamente presentato domanda di adesione, approvata come sotto specificato. Esse sono rappresentate dai loro Presidenti pro-tempore o da loro delegati.

All’atto della sua costituzione, nell'anno 2004, la Federazione riuni' le tre associazioni scientifiche seguenti: AIRO, AMASES, SIMAI. Dall'anno 2017 aderiscono ulteriormente le associazioni scientifiche AILA e AIMETA.

La Federazione garantisce la piena autonomia dei singoli Associati nel perseguimento dei propri fini istituzionali.

Art. 4 (Organi)

Sono organi della Federazione:

- Il Consiglio Direttivo

- Il Presidente

Art. 5 (Composizione e Attribuzioni del Consiglio Direttivo)

Il Consiglio Direttivo è costituito dal Presidente e dai Presidenti pro-tempore delle singole Associazioni afferenti alla Federazione (o loro delegati).

Esso delibera all’unanimità circa l’ammissione di nuovi Associati che abbiano presentato domanda di adesione ai sensi dell’Art. 3. La cessazione degli Associati avviene a seguito di dimissioni o per decisione presa all’unanimità dai restanti Associati.

Il Consiglio Direttivo è responsabile della gestione economica della Federazione.

Il Consiglio Direttivo coordina l’attività della Federazione nel perseguimento dei propri scopi istituzionali.

L’eventuale scioglimento della Federazione deve essere deliberato all’unanimità dal Consiglio Direttivo e l’atto di scioglimento deve essere raccolto in sede notarile. In caso di riduzione degli Associati ad uno solo, sarà esso a deliberare al più presto con le forme sue proprie.

Art. 6 (Nomina e Attribuzioni del Presidente)

La carica di Presidente della Federazione, che viene eletto dal Consiglio Direttivo fra i Presidenti delle Associazioni facenti parte della FIMA eventualmente sostituiti dai corrispondenti delegati, ha la durata di due anni e non puo' essere coperta consecutivamente da membri della stessa Associazione.

Il Presidente presiede le riunioni del Consiglio Direttivo, ha la legale rappresentanza della Federazione di fronte a terzi ed esercita ogni altra attribuzione inerente alla carica, a norma di legge.

Art. 7 (Impegni degli Associati)

Gli Associati si impegnano al rispetto del presente Statuto e delle deliberazioni e regolamenti emanati dagli organi della Federazione.

Gli Organi deliberanti degli Associati stabiliscono un accordo di reciprocità in base al quale i soci di qualsiasi tipologia di ciascuno dei predetti Associati hanno facoltà di iscriversi a Convegni, Congressi, Giornate di lavoro e simili organizzati dagli altri Associati con le medesime condizioni e facilitazioni riservate ai soci dell'Associato che organizza.

Art. 8 (Risorse della Federazione)

Le risorse della Federazione sono costituite da contributi a qualunque titolo ricevuti direttamente, nonche' da quanto deciso di attribuirle da parte dei Consigli Direttivi delle Associazioni afferenti.

In caso di scioglimento, il Consiglio Direttivo delibererà' sulla destinazione delle risorse residue, tenendo conto degli oneri latenti da fronteggiare.

Art. 9 (Modifiche di Statuto)

Il presente Statuto può essere modificato dagli Associati, con decisione unanime.

Art. 10 (Norma conclusiva)

Per tutto quanto non previsto dal presente Statuto si applicano le disposizioni degli Artt. 36 e segg. del Codice Civile e delle leggi vigenti in materia.

Roma, 27 Ottobre 2017

Per AILA, il Presidente, Prof. Antonio Di Nola:

Per AIRO, il Presidente, Prof. Daniele Vigo:

Per AIMETA, *per* il Presidente, Prof. Paolo Luchini, *la* Prof.ssa Sandra Carillo:

Per AMASES, il Presidente, Prof. Bruno Viscolani:

Per SIMAI, il Presidente, Prof. Luca Formaggia:

SIMAI Società Italiana di Matematica Applicata e Industriale

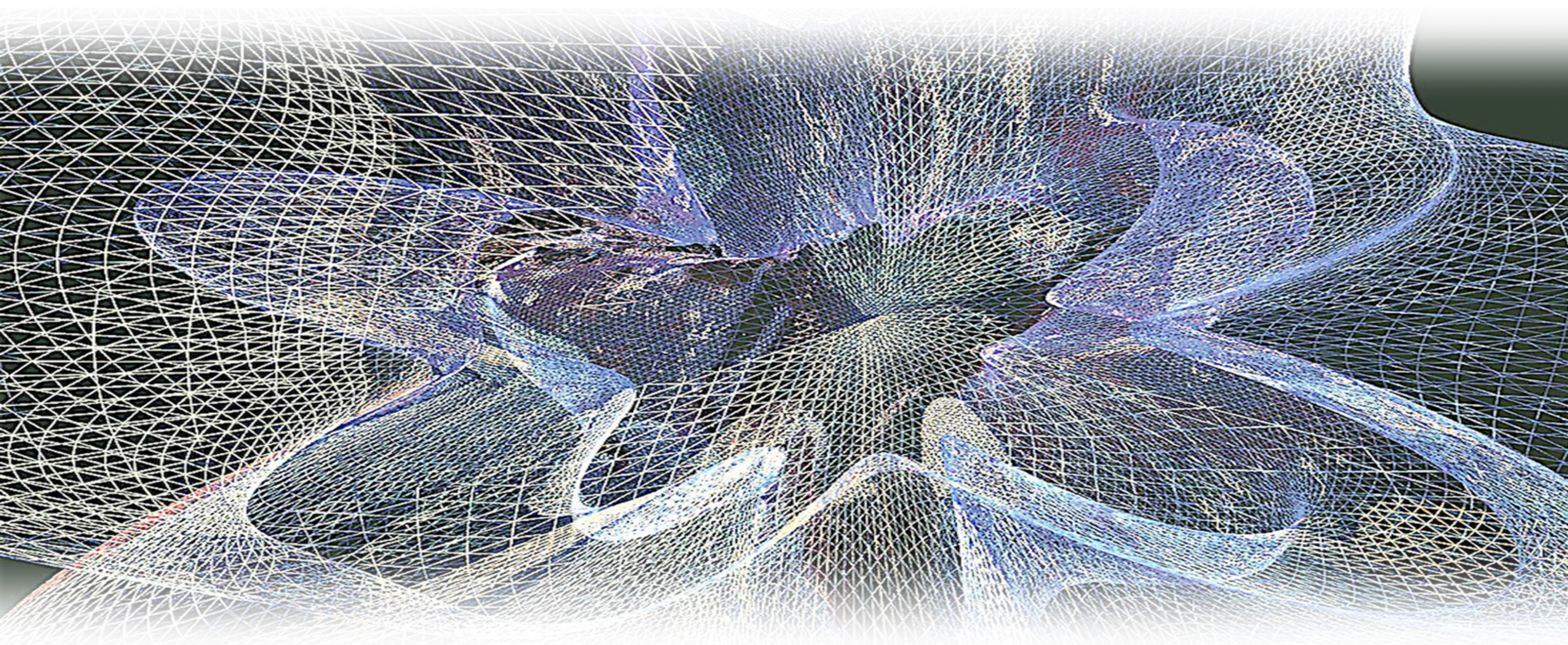
ASSOCIAZIONE PER LA MATEMATICA APPLICATA ALLE SCIENZE ECONOMICHE E SOCIALI

AIRO Associazione Italiana di Ricerca Operativa

GIORNATA DELLA FIMA
FEDERAZIONE ITALIANA DI MATEMATICA APPLICATA

Consiglio Nazionale delle Ricerche

Venerdi 27 Ottobre 2017 ore 10.00
AULA MARCONI – CNR, PIAZZALE ALDO MORO, 7 ROMA



Speakers

SIMAI
Renzo Ricca, Università di Milano Bicocca
Antonio De Simone, SISSA, Trieste

AMASES
Emanuele Borgonovo, Università Bocconi, Milano
Michele Tumminello, Università di Palermo

AIRO
Fabio Schoen Università di Firenze
Laura Palagi, Sapienza Università di Roma

AILA
Silvio Ghilardi, Università di Milano
Hykel Hosni, Università di Milano

AIMETA
Elena Bonetti, Università di Milano
Giuseppe Piccardo, Università di Genova

In collaborazione con
- Sezione di Matematica dell'UNIVERSITÀ TELEMATICA INTERNAZIONALE UNINETTUNO
- Dipartimento di Matematica e Fisica dell'Università RomaTre

UNIVERSITÀ TELEMATICA INTERNAZIONALE UNINETTUNO

PROGRAMMA GIORNATA della FIMA

27 Ottobre 2017, aula Marconi - CNR, Roma

h. 10-10.30: Fabio Schoen Università di Firenze [**AIRO**], "Optimization: a unifying framework for applied problem solving"

h. 10.30-11: Renzo Ricca, Milano Bicocca [**SIMAI**], "Knot polynomials as a new tool for turbulence research".

h. 11-11.30: Silvio Ghilardi, Università di Milano, Dip. di Matematica [**AILA**], "Logica, model checking e verifica formale".

h. 11.30-12: Giuseppe Piccardo, Università di Genova, Dip. Ing. Civile e Amb. [**AIMETA**],"Internal resonances in aeroelastic oscillations".

h. 12-12.30: Emanuele Borgonovo, Bocconi, Milano [**AMASES**], "Big Data and business analytics: a critical overview".

h.12.30-13: Elena Bonetti, Università di Milano [**AIMETA**], "A nonlinear model for marble sulphation including surface rugosity: analytical and numerical results".

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h. 13.00: firma dei Presidenti

PAUSA LUNCH

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h. 14.30-15: Antonio De Simone, SISSA, TS [**SIMAI**], "Biological and bio-inspired motility at microscopic scales".

h. 15-15.30: Laura Palagi, Sapienza Università di Roma [**AIRO**], "Optimization and machine learning".

h. 15.30-16: Michele Tumminello, Università di Palermo [**AMASES**], "Big Data and Networks for Fraud Detection in the Insurance Sector"

h. 16-16.30: Hykel Hosni, Università di Milano, Dip. di Filosofia [**AILA**], "Logica nelle decisioni in condizione di incertezza".

Optimization: a unifying framework for applied problem solving

Fabio Schoen

Roma, October 27, 2017

AIRO

ASSOCIAZIONE ITALIANA DI RICERCA OPERATIVA

Outline

- Foreword
- Optimization everywhere . . .
- Brief introduction to the Global Optimization Laboratory Univ. of Florence

Part I

Foreword

(personal view): Milestones in Applied Optimization

(personal view): Milestones in Applied Optimization

(personal view): Milestones in Applied Optimization: Didone

Devenere locos ubi nunc ingentia cernis
Moenia sergentemque novae Karthaginis arcem,
mercatique, solum, facti de nomine Byrsam,
taurino quantum possent circumdare tergo.

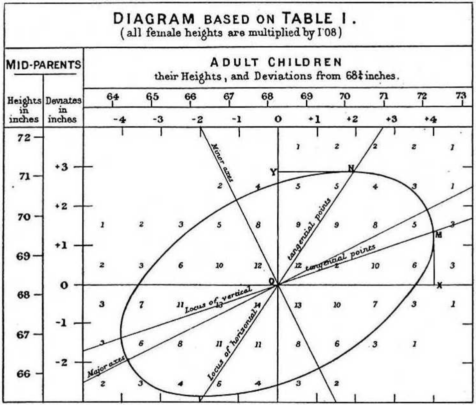
Giunsero in questi luoghi, ov'or vedrai
sorger la gran cittade e l'alta rocca
della nuova Carthago, che dal fatto
Birsa nomassi, per l'astuta merce
che, per fondarla, fèr di tanto sito
quanto cerchiar di bue potesse un tergo

Virgilio, Eneide

(personal view): Milestones in Applied Optimization: G.B. Dantzig

In the summer of 1947, when I began to work on the simplex method for solving linear programs, the first idea that occurred to me is one that would occur to any trained mathematician, namely the idea of step-by-step descent (with respect to the objective function) along edges of the convex polyhedral set from one vertex to an adjacent one. I rejected this algorithm outright on intuitive grounds-it had to be inefficient because it proposed to solve the problem by wandering along some path of outside edges until the optimal vertex was reached. I therefore began to look for other methods that gave more promise of being efficient, such as those that went directly through the interior [4].
George G.B. Dantzig

(personal view): Milestones in Applied Optimization: Sir Francis Galton



(personal view): Milestones in Applied Optimization: McCulloch and Pitts

BULLETIN OF
MATHEMATICAL BIOPHYSICS
VOLUME 5, 1943

A LOGICAL CALCULUS OF THE IDEAS IMMANENT IN NERVOUS ACTIVITY

WARREN S. MCCULLOCH AND WALTER PITTS

FROM THE UNIVERSITY OF ILLINOIS, COLLEGE OF MEDICINE,
DEPARTMENT OF PSYCHIATRY AT THE ILLINOIS NEUROPSYCHIATRIC INSTITUTE,
AND THE UNIVERSITY OF CHICAGO

Because of the "all-or-none" character of nervous activity, neural events and the relations among them can be treated by means of propositional logic. It is found that the behavior of every net can be described in these terms, with the addition of more complicated logical means for nets containing circles; and that for any logical expression satisfying certain conditions, one can find a net behaving in the fashion it describes. It is shown that many particular choices among possible neurophysiological assumptions are equivalent, in the sense that for every net behaving under one assumption, there exists another net which behaves under the other and gives the same results, although perhaps not in the same time. Various applications of the calculus are discussed.

Part II

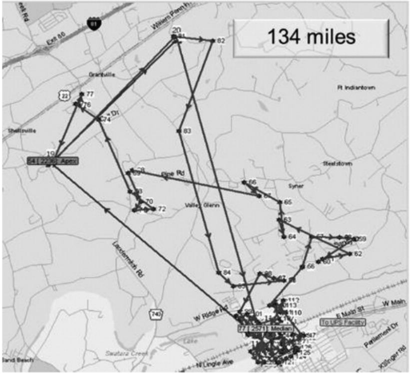
Applied Optimization:

Part II

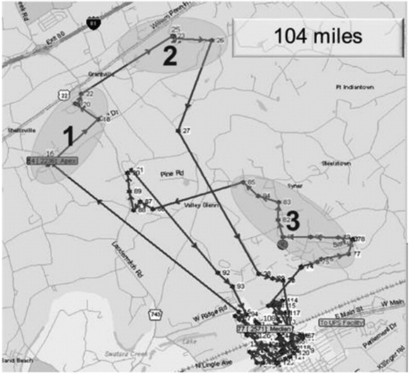
Applied Optimization: INFORMS Edelman Prize

UPS Optimizes Delivery Routes

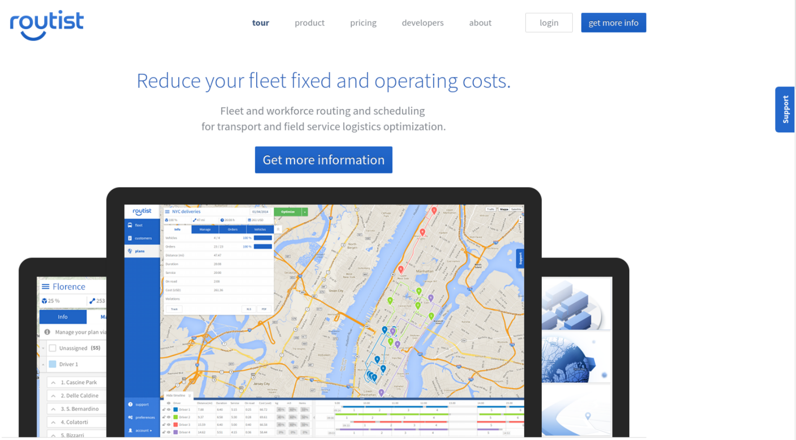
Driver's Solution



ORION Solution

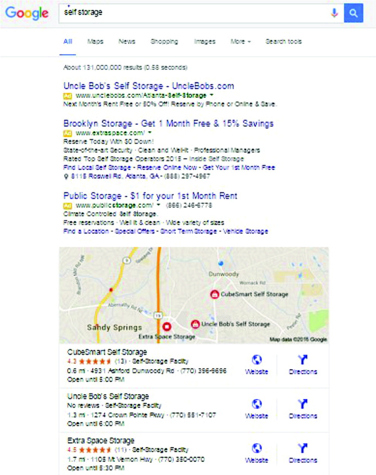


KKT srl, now a Verizon company



360i Generates Nearly $1 Billion in Revenue for Internet Paid-Search Clients

Optimization models for: forecasting, budget allocation, bidding



Bank of NY Mellon Optimization Reduces Intraday Credit Risk by $1.4 Trillion

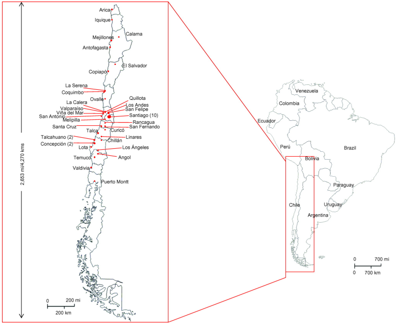
A set of integrated mixed-integer programming models to solve collateral-management challenges involving short-term secured loans.

Minimize intraday credit exposure and the liquidity usage of its clients.

Each day rebalancing and continuous portfolio optimization employed to process $1.4 trillion of client collateral.

Reduced intraday credit risk by more than 97%

Operations Research Transforms the Scheduling of Chilean Soccer Leagues and South American World Cup Qualifiers



Optimize cost & audience taking constraints into account

Scheduling the Italian Volley Championship

Video on YouTube: `https://youtu.be/9A35btfoGlo`

2017 Edelman Prize winner and finalists

Holiday Retirement

(security, confort and valu to seniors)
Senior Living Rent Optimizer, the first revenue management system in the industry.

American Red Cross

Barco

(visualization and image processing solutions)

2017 Edelman Prize winner and finalists

BHP Billiton

(discovery, acquisition, development and marketing of natural resources, e.g., mineral extraction, petroleum)

General Electric

(mission: build, power, cure, move, and connect the world)

New York City Department of Transportation

Part III

GOL: Global Optimization Laboratory

GOL: who we are

2 professor, one researcher, 7 PhD students, 1 post-doc
Many students. . .

GOL - Global Optimization Laboratory

Recent Research Projects (EU, Tuscany Region):

- (2016-) *LINFA - Logistica Intelligente del Farmaco*: optimal decisions in drug replenishment at hospital wards
- (2015-) *SiiMobility – Supporto all'interoperabilità integrata per i servizi ai cittadini e alla pubblica amministrazione*: optimal path planning for multi-modal multi-objective paths (foot, car, bike, wheelchair, . . .)
- (2014) *PRESTIGE – Progetto di RicErca e Sviluppo di servizi Turistici Innovativi basati su architettura abilitante attuato da un Gruppo di opEratori sinergici*: optimization of touristic tours
- (2013-2015) *SMARTY – Smart Transportation for sustainable city*: optimal relocation in bike sharing systems, optimal traffic equilibrium
- (2013) *MIDA: Machine Intelligence for Diagnosys Automation*: optimal prediction of machine failures from oil analyses

GOL - Global Optimization Laboratory

Recent Research Projects (private companies):

- (2016-2017): *ENEL: modelli di previsione della produzione fisica e dell'offerta a mercato di impianti rinnovabili* machine learning for optimal prediction in the energy market
- (2014-2016): *Kering / Gucci*: Demand forecasting, optimal inventory planning, optimal replenishment decisions
- (2015-2016) *KKT*: optimization for vehicle routing
- (2016-2017) *Lega Volley*: Optimal scheduling of the Italian League Volley Tournament

Our future

HOME INTL NEWS MARKETS INVESTING TECH MAKE IT VIDEO SHOW

The Sexiest Job of the 21st Century: Data Analyst

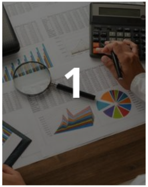
Chris Morris, Special to CNBC.com
Published 1:00 PM ET Wed, 5 June 2013 | Updated 4:50 PM ET Wed, 5 June 2013

Photo: Biddlboo | Getty Images

Looking for a career change or a college major that's all but guaranteed to result in a hefty salary with copious benefits? Big data may not seem the obvious choice, but it could be your best.

With more and more companies using big data, the demand for data

Best jobs ranking 2017 - CAREERCAST



Statistician

Overall Rating: 1/199 — **Median Salary:** $80,110

Work Environment	Stress	Projected Growth
Very Good	Very Low	Very Good
4/199	39/199	3/199

View Raw Scores

Search Statistician Jobs

Medical Services Manager

Overall Rating: 2/199 — **Median Salary:** $94,500

Work Environment	Stress	Projected Growth
Very Good	Very Low	Very Good
23/199	17/199	32/199

View Raw Scores

Search Medical Services Manager Jobs

Operations Research Analyst

Overall Rating: 3/199 — **Median Salary:** $79,200

Work Environment	Stress	Projected Growth
Very Good	Very Low	Very Good
35/199	10/199	6/199

View Raw Scores

Search Operations Research Analyst Jobs

Optimization: a unifying framework for applied problem solving

Fabio Schoen

Roma, October 27, 2017

AIRO

ASSOCIAZIONE ITALIANA DI RICERCA OPERATIVA

Rome – 27 October, 2017

Knot polynomials as a new tool for turbulence research

RENZO L. RICCA

Department of Mathematics & Applications, U. Milano-Bicocca, Italy

renzo.ricca@unimib.it

Objectives

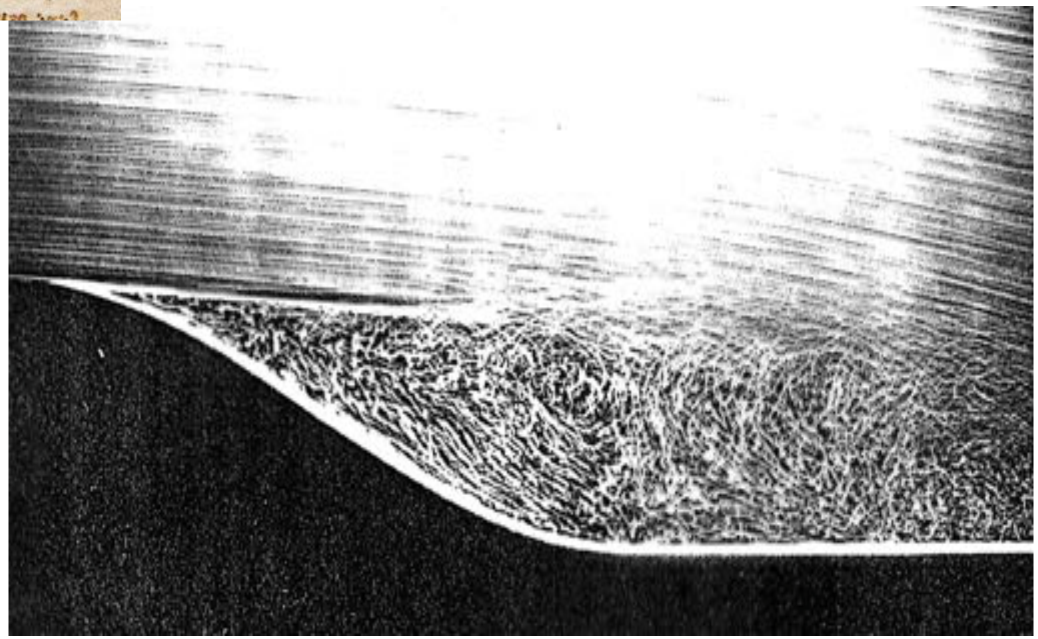
- *Determine relationships between structural complexity of physical knots and energy;*
- *Quantify energy/helicity transfers in dynamical systems.*

- *Knot polynomials as new physical invariants to quantify topological complexity;*
- *Extend and apply new topological techniques to study complex systems.*

$\mathcal{T}$

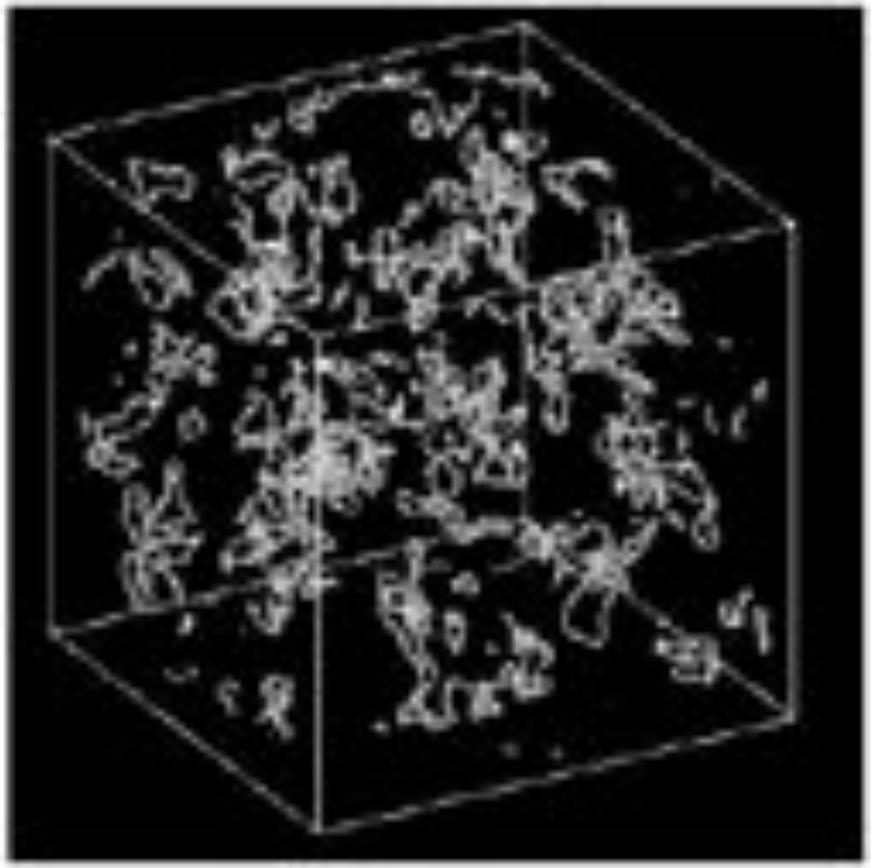
Coherent structures

Leonardo da Vinci
(Water Studies 1506)

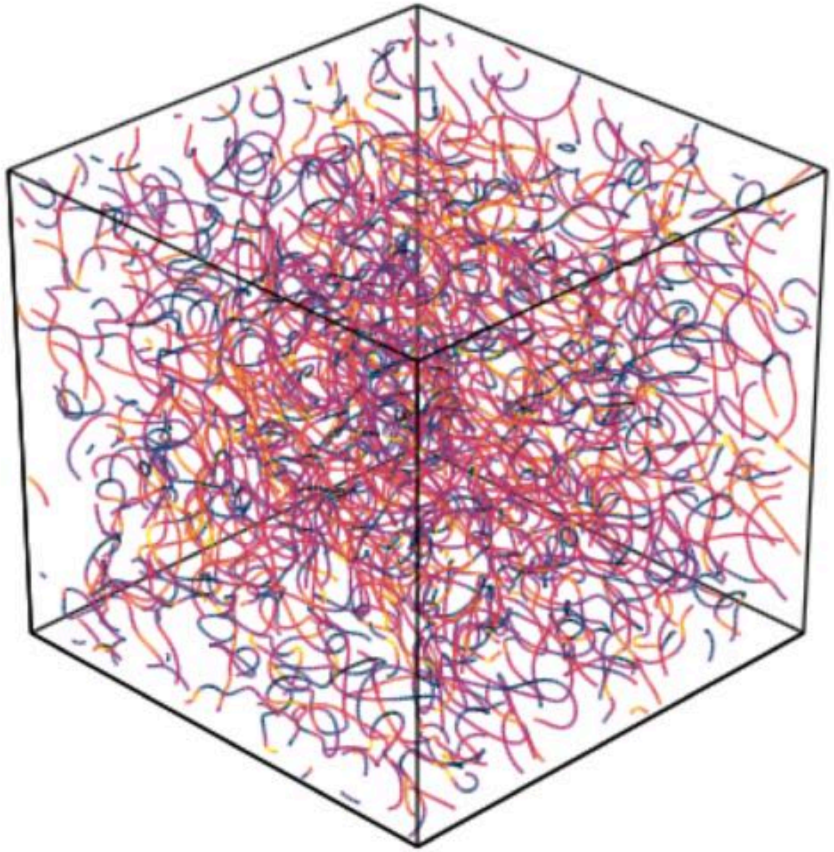


Werlé, ONERA, 1974
(Van Dyke 1982)

Vorticity localization in quantum fluids



Miyazaki et al. (Physica D 2009)



Laurie & Baggaley (JLTP 2015)

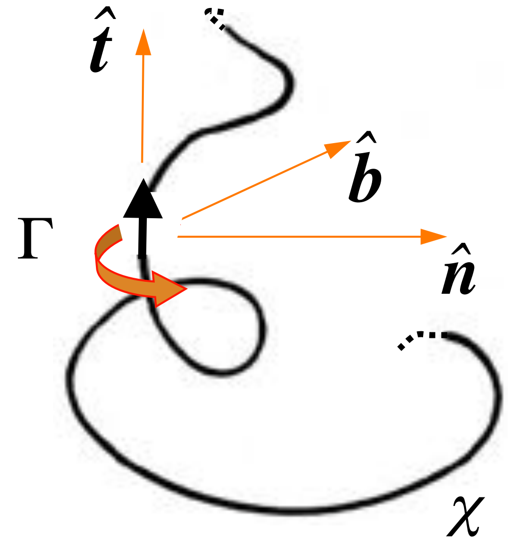
Modeling vortex tangles by filaments

homogeneous
incompressible
inviscid
$\Bigg\}$ *fluid in* $\mathbb{R}^3$ **:** $\quad \boldsymbol{u} = \boldsymbol{u}(\boldsymbol{X}, t) \quad \begin{cases} \nabla \cdot \boldsymbol{u} = 0 & \text{in } \mathbb{R}^3 \\ \boldsymbol{u} = 0 & \text{as } \boldsymbol{X} \to \infty \end{cases}$

- ***Vortex line*** χ **:** ***vorticity:*** $\boldsymbol{\omega} = \nabla \times \boldsymbol{u}$,

$$\boldsymbol{\omega} = \varpi_0 \hat{\boldsymbol{t}} \ , \quad \varpi_0 = \text{constant} \ ;$$

circulation: $\Gamma = \text{constant}$.



Vortex tangle: $\mathcal{T} = \bigcup_i \chi_i \quad i = 1, \ldots, N$.

- ***Kinetic energy:*** $E(\mathcal{T}) = \int_\Omega \boldsymbol{u} \cdot (\boldsymbol{X} \times \boldsymbol{\omega}) \, \mathrm{d}^3 \boldsymbol{X}$

from Lamb (1932), we have:

$$E(\mathcal{T}) \approx \frac{\Gamma^2}{4\pi} \sum_{ij} \iint_{\chi_i \chi_j} \frac{\hat{\boldsymbol{t}}_i \cdot \hat{\boldsymbol{t}}_j}{|\boldsymbol{X}_i - \boldsymbol{X}_j|} \, \mathrm{d}s_i \mathrm{d}s_j \ .$$

- ***Total length of vortex tangle given by*** $L(\mathcal{T}) = \sum_i \int_{\chi_i} \hat{\boldsymbol{t}}_i \, \mathrm{d}s_i$.

Kinetic helicity and linking numbers

- ***Kinetic helicity:***

$$H(\mathcal{T}) = \int_{\mathcal{T}} \boldsymbol{u}\cdot\boldsymbol{\omega}\, \mathrm{d}^3\boldsymbol{X} = \Gamma \sum_i \int_{\chi_i} \boldsymbol{u}\cdot \mathrm{d}\boldsymbol{l} \ .$$

- ***Theorem* (*Moffatt 1969; Moffatt & Ricca 1992*)*. Let* $\mathcal{T}$ *be an essential physical link in an ideal fluid. Then, we have:***

$$H(\mathcal{T}) = \Gamma^2\left(\sum_i SL_i + \sum_{i\neq j} Lk_{ij}\right)$$

$$\begin{cases} SL_i = SL(\chi_i) & \textit{self-linking number} \\ Lk_{ij} = Lk(\chi_i, \chi_j) & \textit{linking number} \end{cases}$$

- ***Self-linking number (Călugăreanu-White invariant):***

Consider the ribbon $\Re(\chi,\chi^*)$ ***; then*** $SL = \lim_{\varepsilon\to 0} Lk(\chi,\chi^*)$ ***,***
where

$$SL = Wr(\chi) + Tw(\chi,\chi^*) \ ,$$

writhing number: $Wr(\chi)$

total twist number: $Tw(\chi,\chi^*)$

Tackling structural complexity by knot polynomials

- ***Helicity and linking number limitations:***

(i) $$H(\mathcal{T}) = f\left(SL_i, Lk_{ij}; \Gamma\right)$$

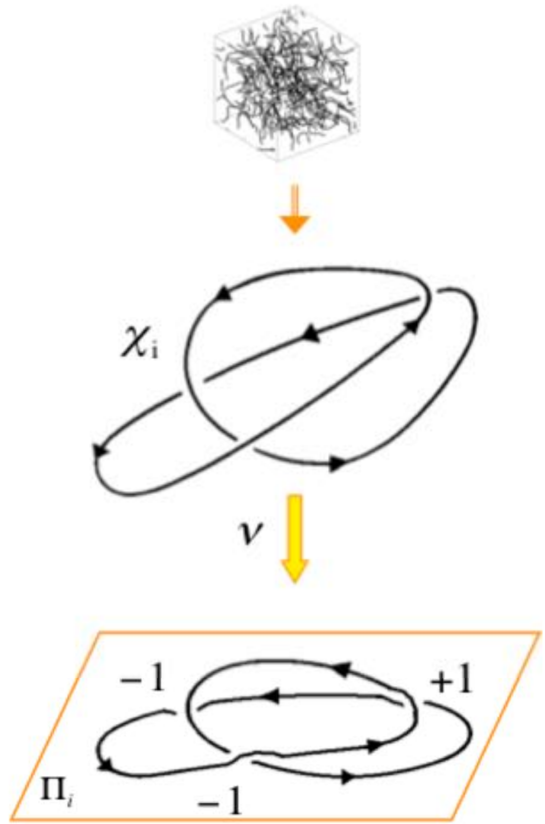
(ii) $$Lk_{ij} = 0\,, \quad \sum_{i\neq j} Lk_{ij} = 0\,.$$

- ***HOMFLYPT polynomial*** $P\left(\chi\right) = P_\chi(a,z)$:

(P.1) $$P\left(\mathrm{O}\right) = 1$$

(P.2) aP  $- a^{-1}P$  $= zP$ 

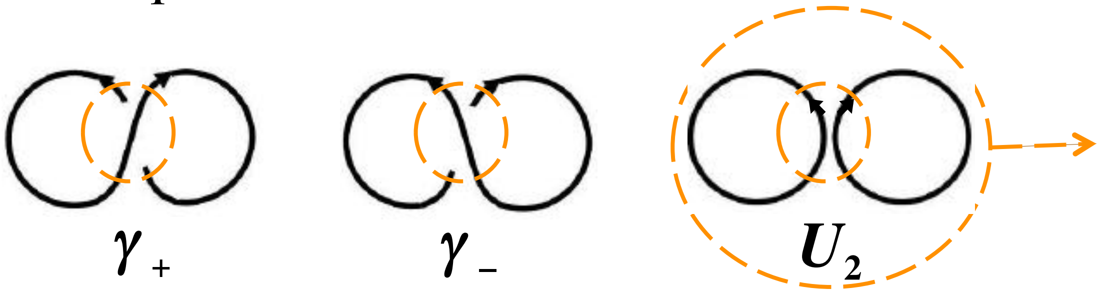
\+   –   =



P.1: 

U_1 γ_+ γ_-

$$P\left(\mathrm{O}\right) = P\left(\gamma_+\right) = P\left(\gamma_-\right) = 1$$

P.2: 

γ_+ γ_- U_2

$$P\left(U_2\right) = \frac{a - a^{-1}}{z}$$

HOMFLYPT polynomial from self-linking

- ***Theorem (Liu & Ricca, JFM 2015). If χ denotes a vortex knot of helicity $H = H(\chi)$, then***

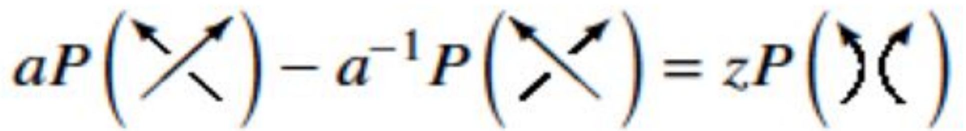
$$e^{H(\chi)} = e^{SL(\chi)} ,$$

appropriately rescaled, satisfies (with a plausible statistical hypothesis) the skein relations of the HOMFLYPT polynomial $P(\chi) = P_\chi(a,z)$.

- ***HOMFLYPT variables in terms of writhe and twist:***

$$a = f(Tw) , \qquad z = g(Wr) .$$

Hence, from the HOMFLYPT (P.2) skein relation, we have:



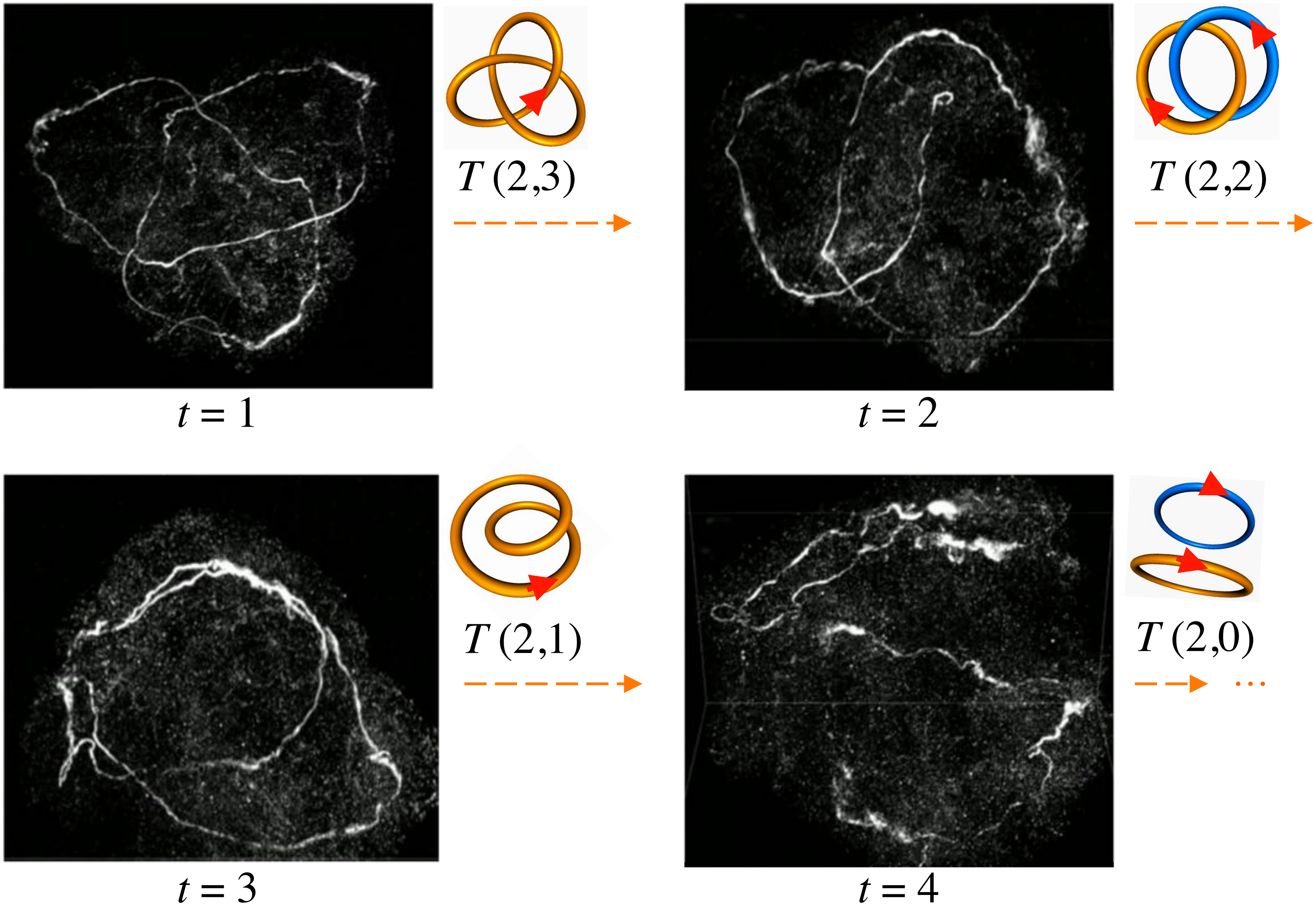
$$\left[f(Tw)\right] = g(Wr) .$$

- ***Reduction of HOMFLYPT $P_\chi(a,z)$ to Jones $V_\chi(t)$:***

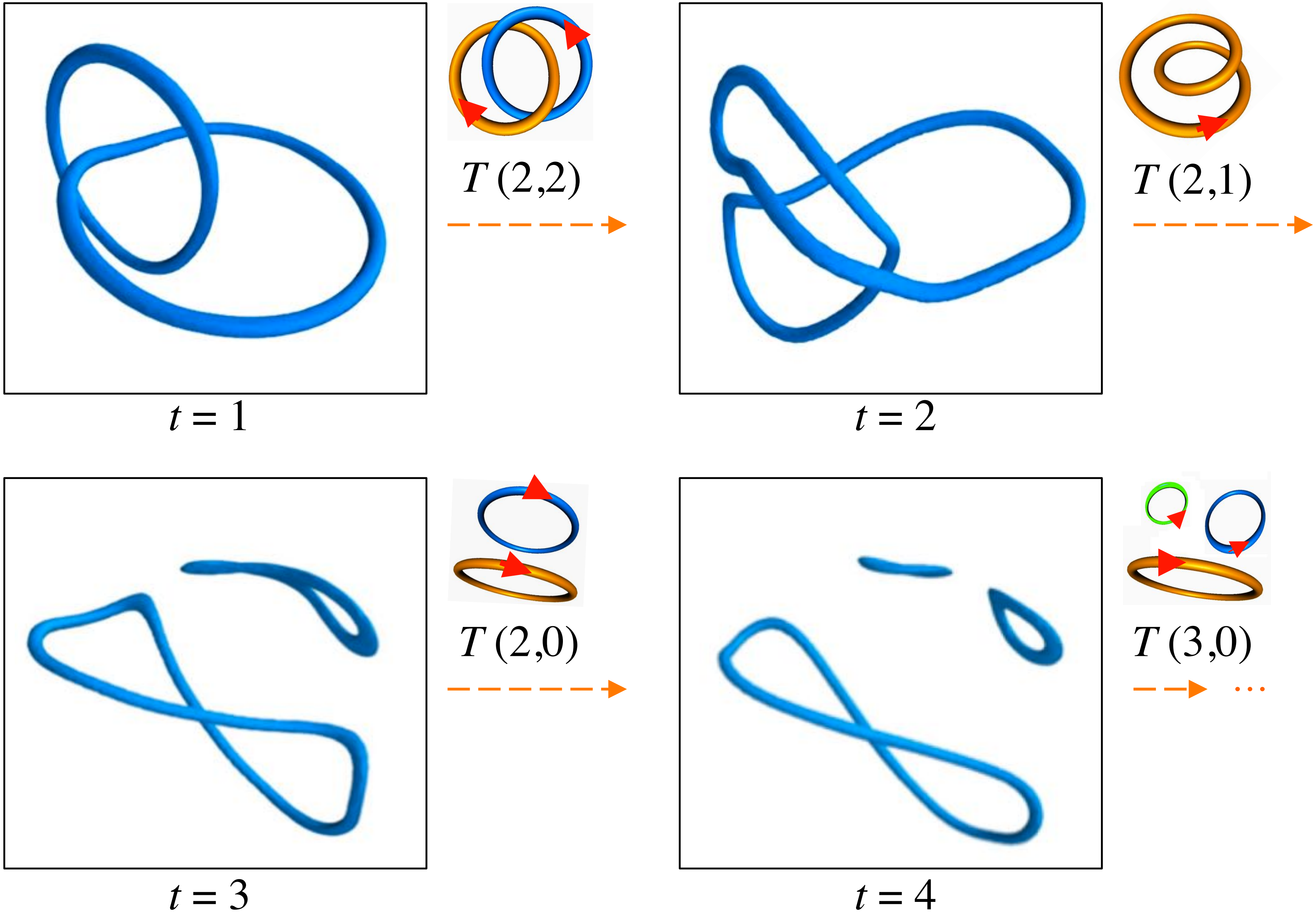
$$t = h(a,z) \ : \qquad Wr \propto Tw$$

knots and links are "framed".

Vortex trefoil cascade process in water (Kleckner & Irvine 2013)



Quantum vortex link cascade in BECs (Zuccher & Ricca, PRE 2017)

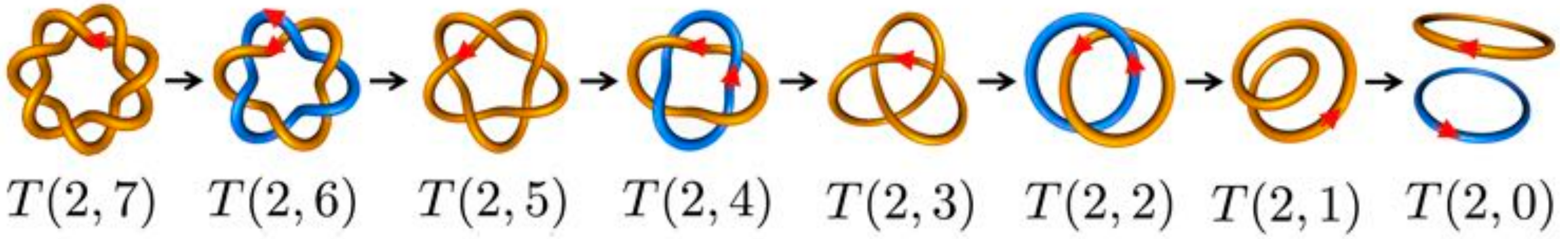


Torus knots & links cascade modeling

Consider the cascade process:

(i)

(ii) ...



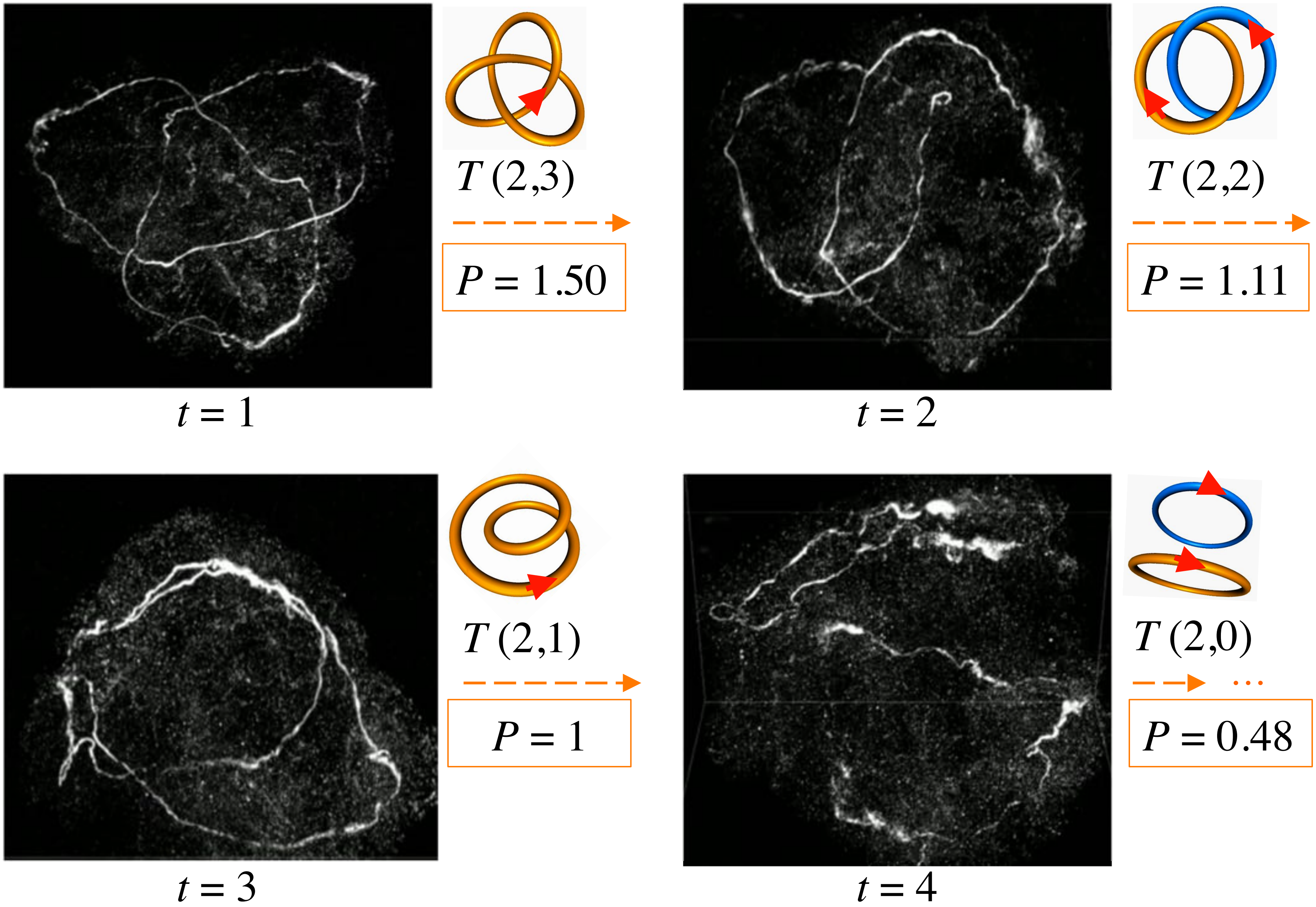
$$\{T(2,n)\}: \quad \ldots \to T(2,2n+1) \to T(2,n) \to \ldots \to T(2,0)\ .$$

- ***Theorem (Liu & Ricca, Nature Sci Rep 2016). HOMFLYPT computation of*** $P_{T(2,n)}$ ***generates, for decreasing*** n***, a monotonically decreasing sequence of numerical values given by***

$$P_{T(2,3+q)} = A_q(\tau,\omega)P_{T(2,3)} + B_q(\tau,\omega)P_{T(2,2)} \quad (q \in \mathbb{N})\ ,$$

where $A_q(\tau,\omega)$ ***and*** $B_q(\tau,\omega)$ ***are known functions of*** τ ***and*** ω***, with initial conditions*** $P_{T(2,3)}$ ***and*** $P_{T(2,2)}$.

Vortex trefoil cascade process in water (Kleckner & Irvine 2013)



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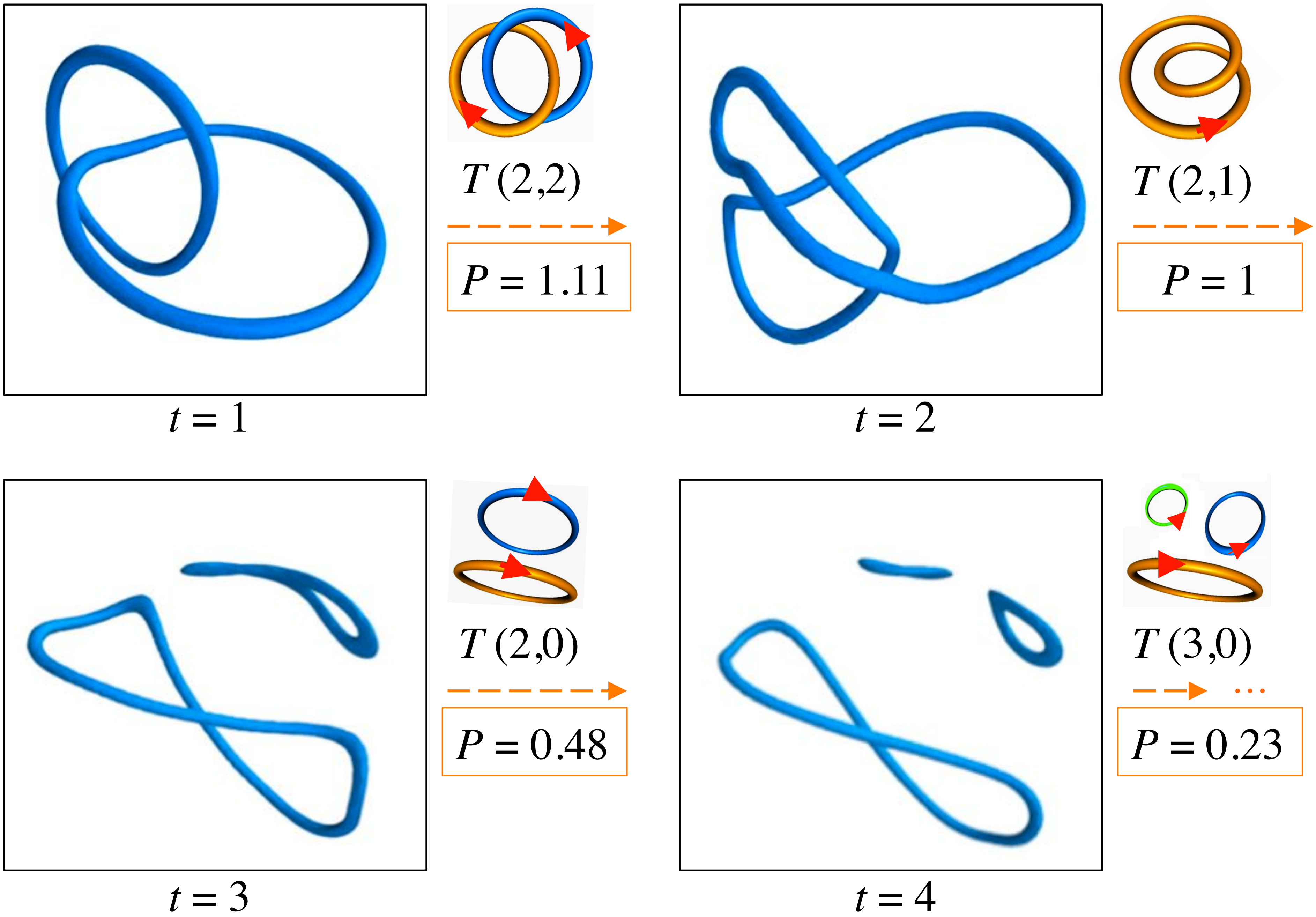
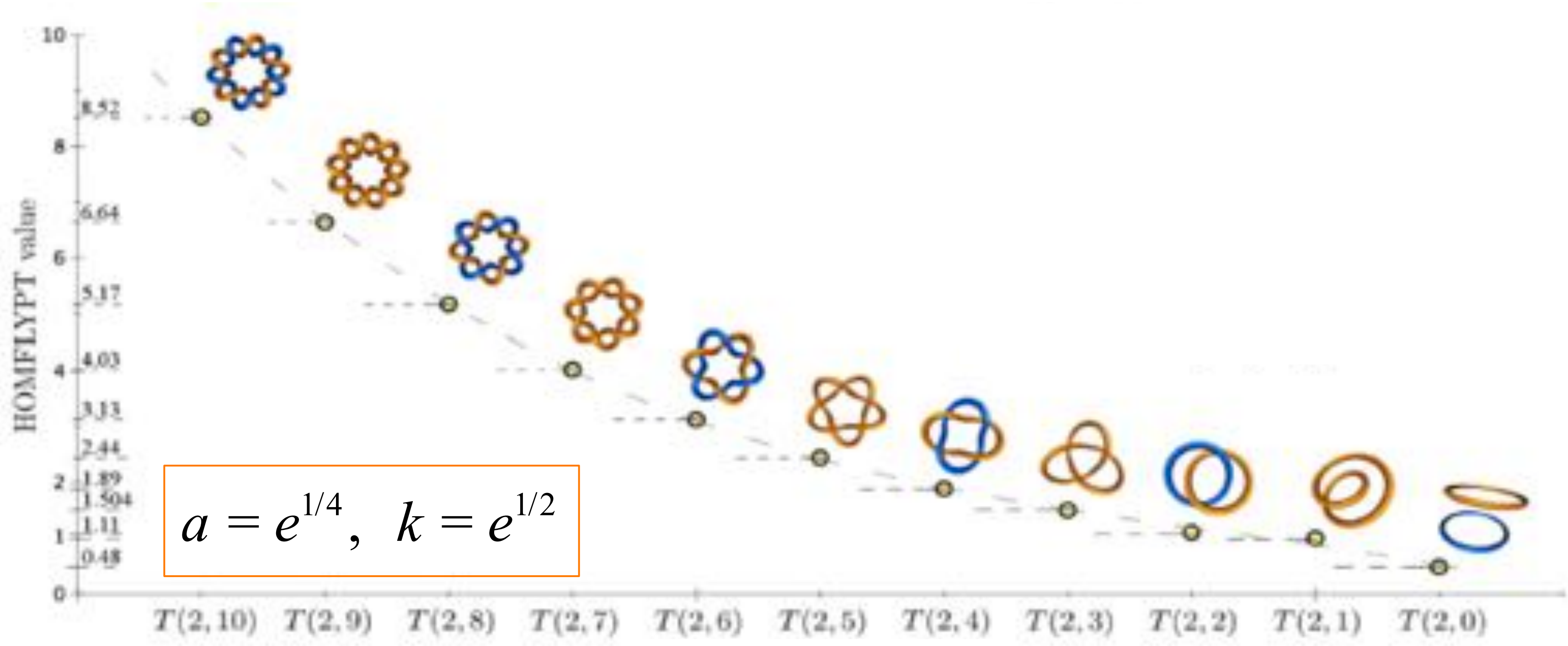


HOMFLYPT quantifies topological complexity



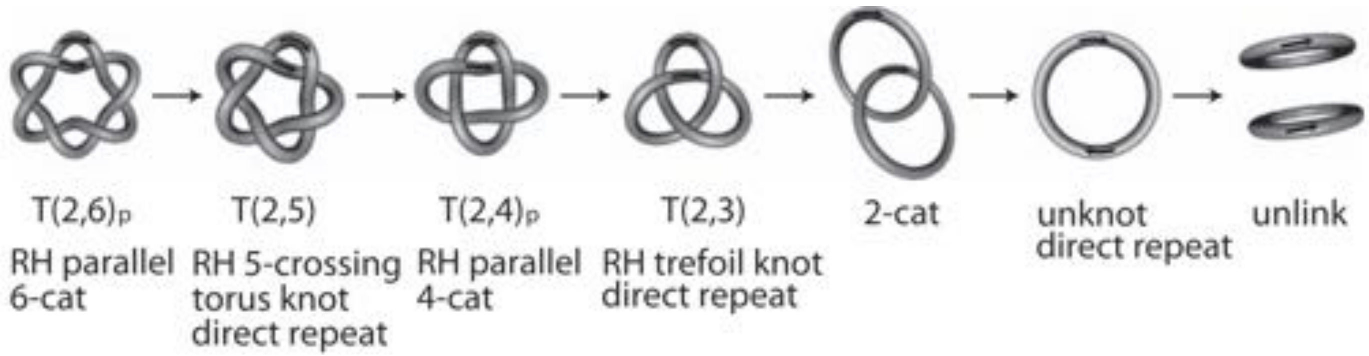
- ***Comparative analysis: HOMFLYPT versus other knot polynomials***

Numerical values for torus knots and *co-oriented* torus links ($Wr = Tw = 1/2$)											
	$T(2,10)$	$T(2,9)$	$T(2,8)$	$T(2,7)$	$T(2,6)$	$T(2,5)$	$T(2,4)$	$T(2,3)$	$T(2,2)$	$T(2,1)$	$T(2,0)$
HOMFLYPT: $a = e^{1/4}, k = e^{1/2}$	8.52	6.64	5.17	4.03	3.13	2.44	1.89	1.50	1.11	1	0.48
Jones: $t = e^{-1}$	–0.01	0.02	–0.03	0.05	–0.09	0.15	–0.25	0.40	–0.69	1	–2.26
Alexander-Conway: $\varsigma = e^{-1}$	–65.81	39.92	–24.20	14.70	–8.88	5.44	–3.22	2.08	–1.04	1	-

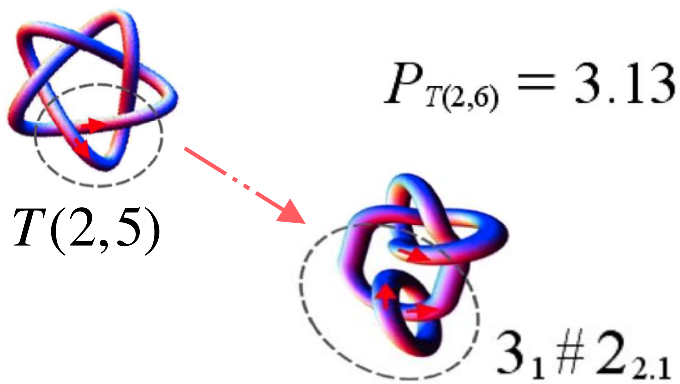
Conclusions and outlook

- ***Adapted HOMFLYPT is the best quantifier of cascade processes:***
  - ***P_K provides monotonic behavior consistently;***
  - ***numerical values more robust and reliable markers for diagnostics.***

- ***Same cascade in recombinant DNA plasmids (Shimokawa et al. 2013):***



- ***Optimal path to cascade?***



$$P_{T(2,6)} = 3.13 \rightarrow P_{T(2,5)} = 2.44 \rightarrow P_{T(2,4)} = 1.89 \rightarrow P_{T(2,3)} = 1.50$$

$$P_{T(2,6)} = 3.13 \rightarrow P_{3_1\#3_1} = 2.26 \rightarrow P_{3_1\#2_{2.1}} = 1.66 \rightarrow P_{T(2,3)} = 1.50$$

LOGICA
MODEL CHECKING
VERIFICA FORMALE

Silvio Ghilardi

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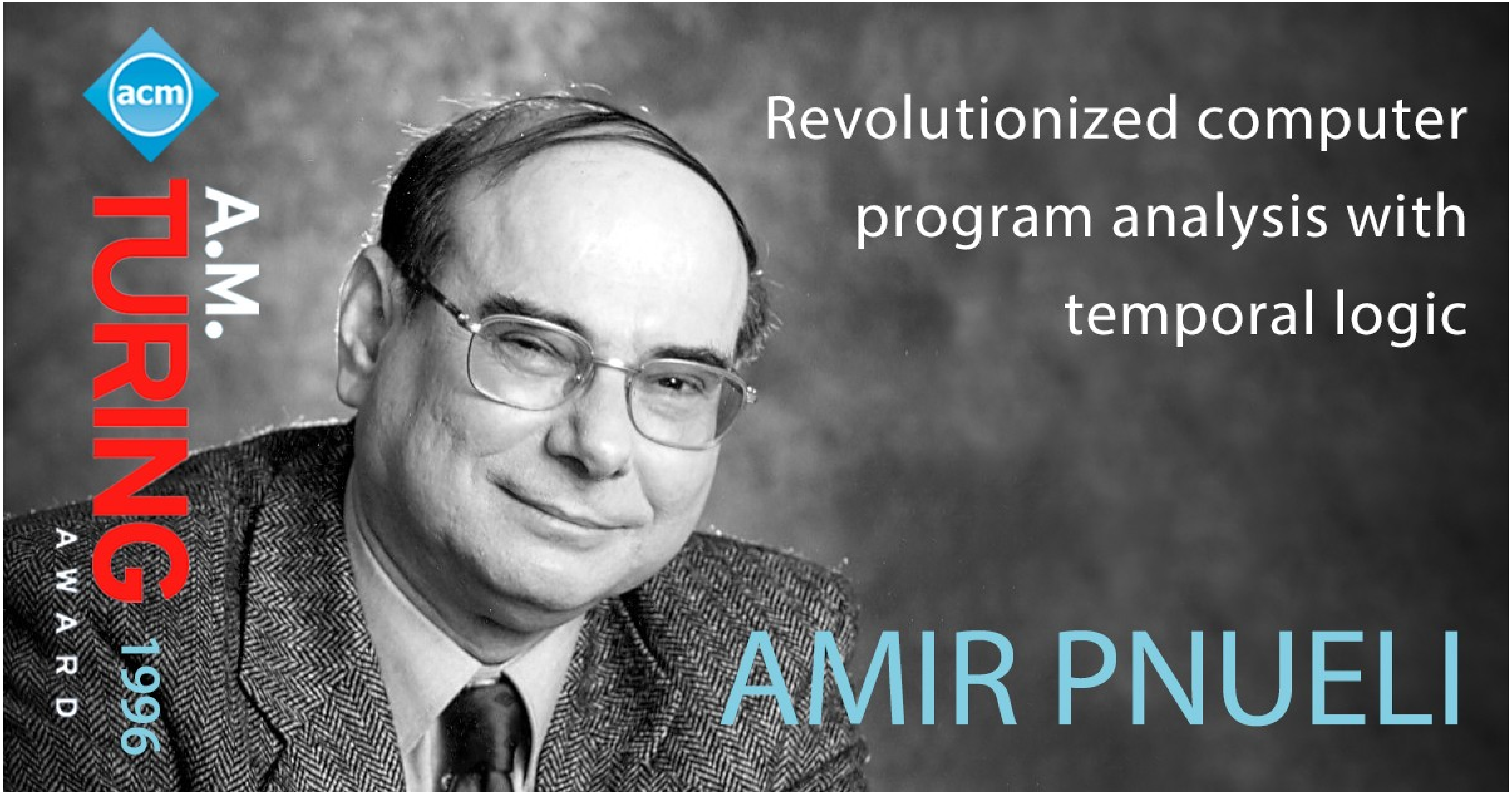
http://users.mat.unimi.it/users/ghilardi/

A BIT OF HISTORY


acm
A.M.
TURING
AWARD
1996
Revolutionized computer
program analysis with
temporal logic
AMIR PNUELI

While working at the department of computer science at Tel Aviv University, Amir Pnueli became deeply involved in logics and deductive methods, and particularly in the work of Arthur Prior. Pnueli became the first to realize the potential implications of applying Prior's “tense logic” to computer programs. **Pneuli’s 1977 seminal paper, “The Temporal Logic of Programs,” revolutionized the way computer programs are analyzed**. At the time, **practical program verification was widely considered to be hopeless, but Pnueli’s paper introduced the notion of reasoning about programs as execution paths, breathing new life into the field of program verification**. For this visionary work combining temporal logic with computing science, Pnueli received the 1996 ACM A.M. Turing Award.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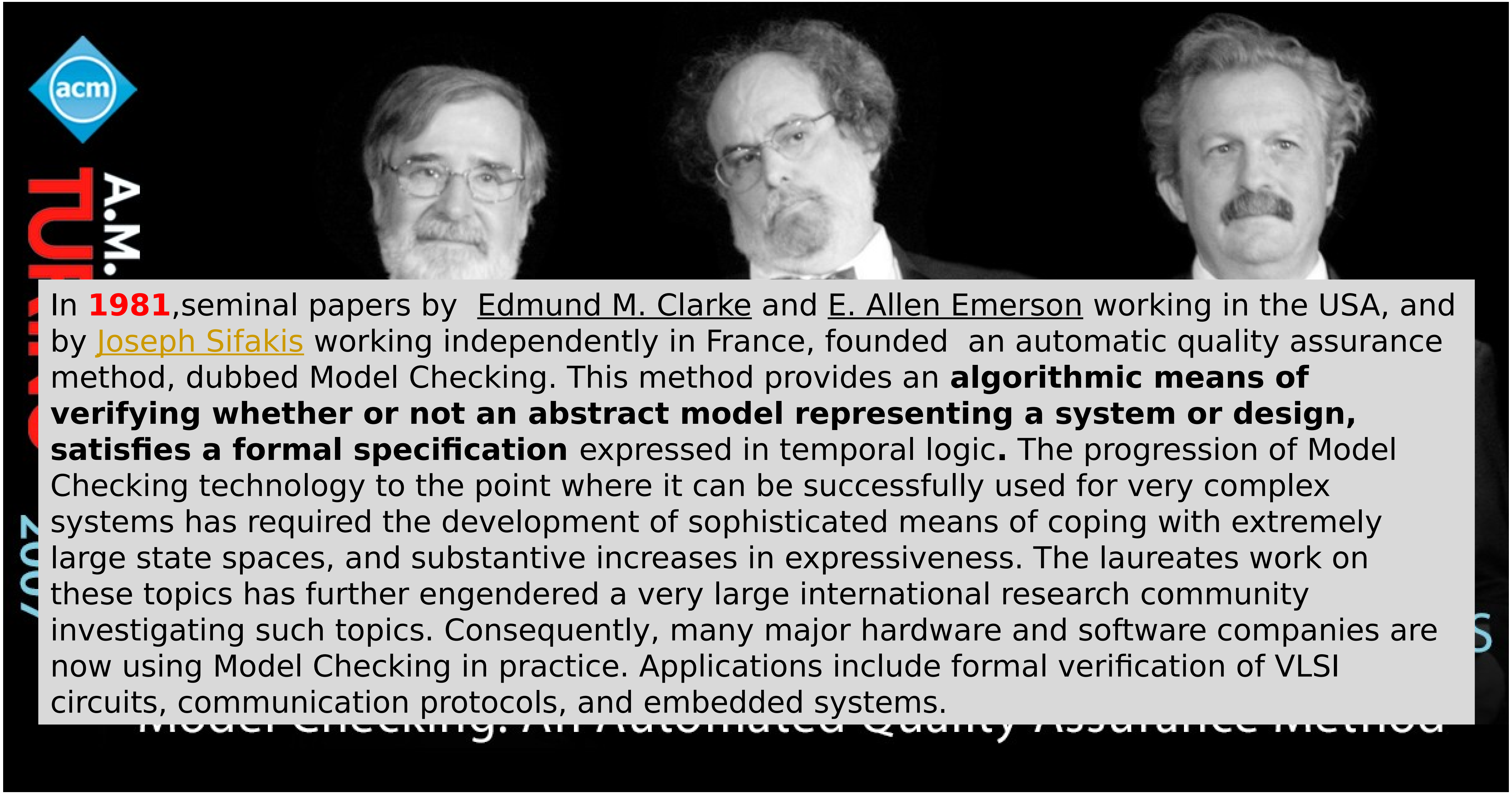
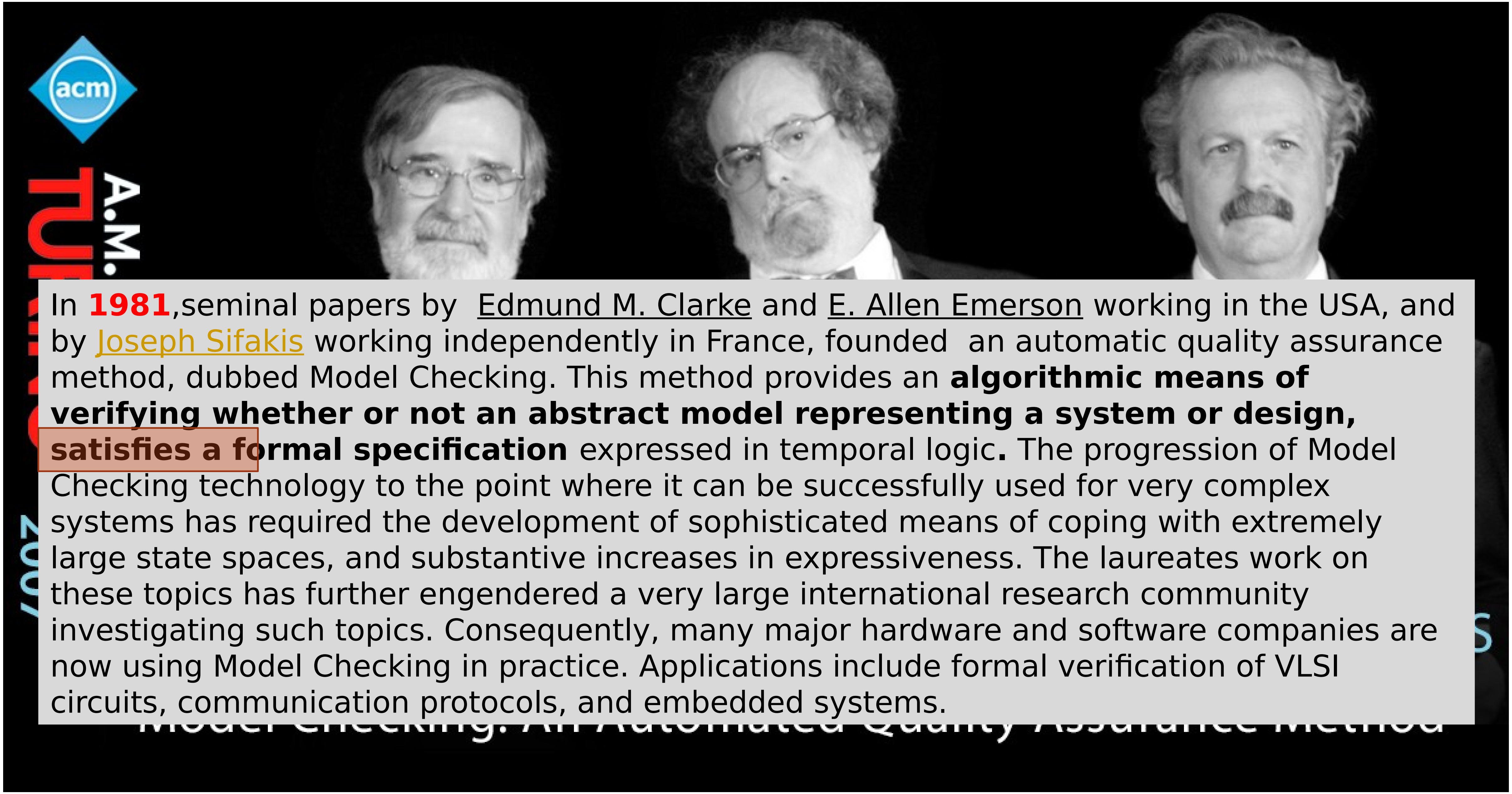
AWARD
2007
EDMUND M. CLARKE, E. ALLEN EMERSON, JOSEPH SIFAKIS
Model Checking: An Automated Quality Assurance Method



In **1981**,seminal papers by Edmund M. Clarke and E. Allen Emerson working in the USA, and by Joseph Sifakis working independently in France, founded an automatic quality assurance method, dubbed Model Checking. This method provides an **algorithmic means of verifying whether or not an abstract model representing a system or design, satisfies a formal specification** expressed in temporal logic**.** The progression of Model Checking technology to the point where it can be successfully used for very complex systems has required the development of sophisticated means of coping with extremely large state spaces, and substantive increases in expressiveness. The laureates work on these topics has further engendered a very large international research community investigating such topics. Consequently, many major hardware and software companies are now using Model Checking in practice. Applications include formal verification of VLSI circuits, communication protocols, and embedded systems.



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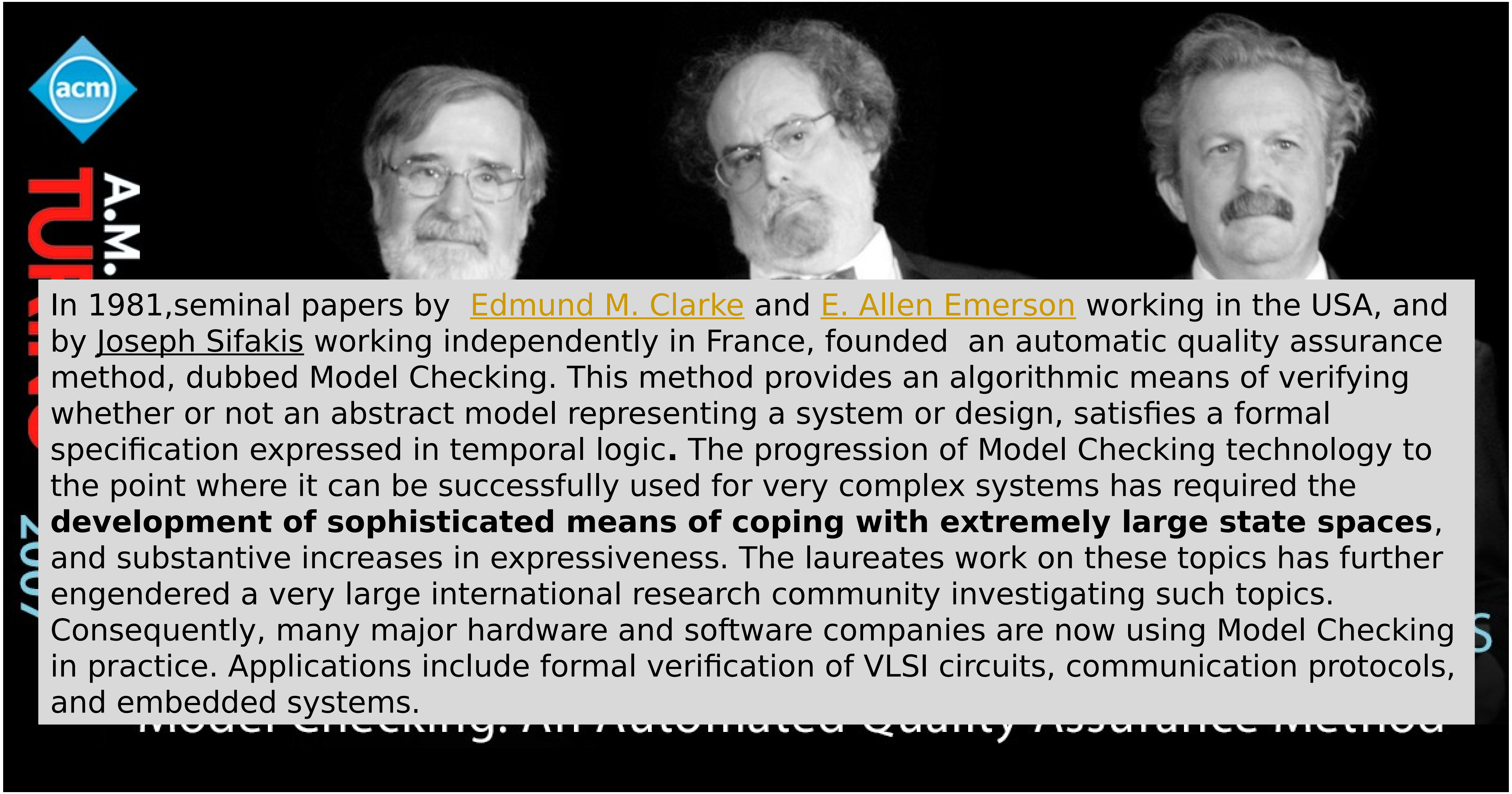

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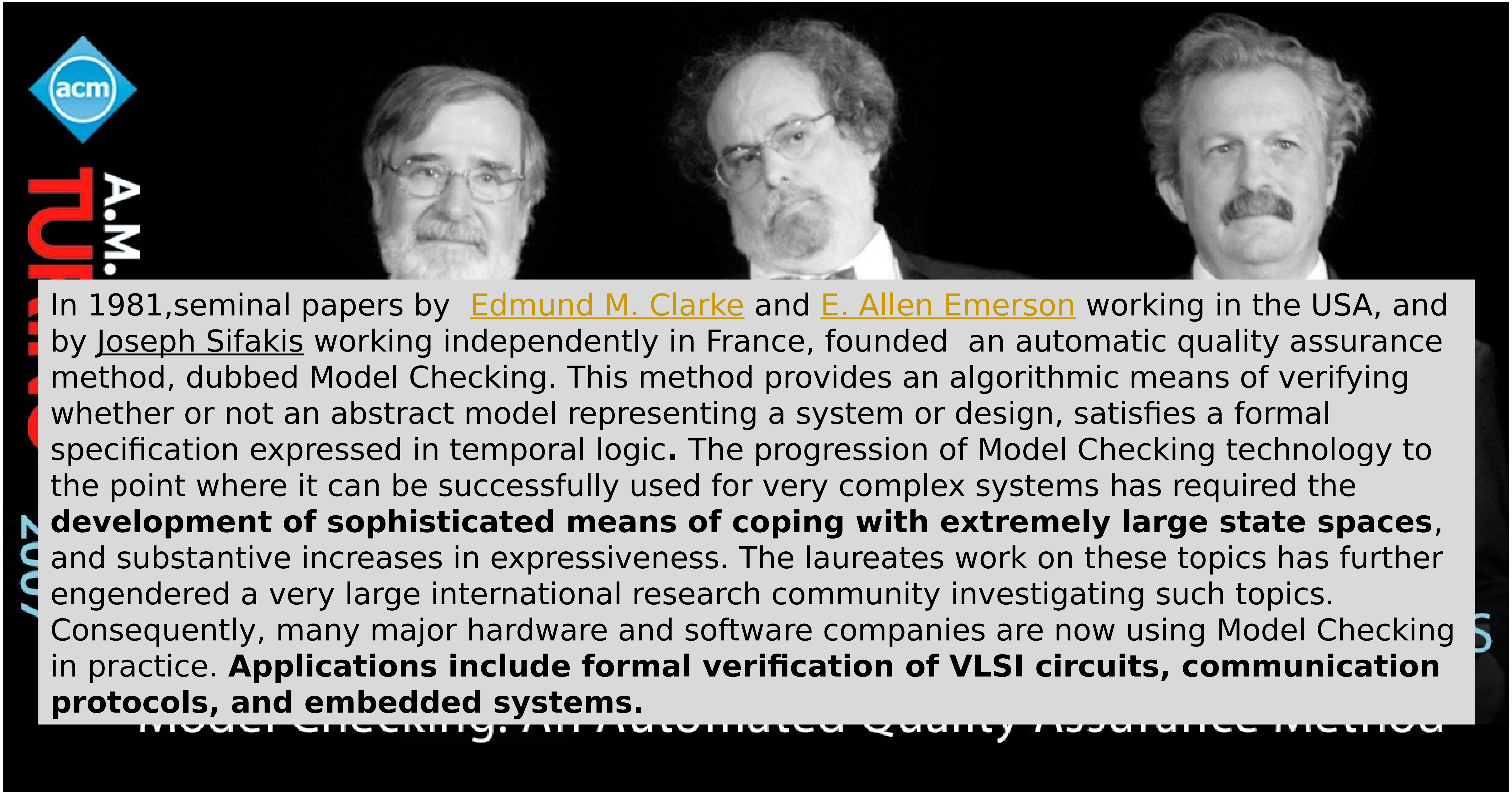

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MODEL CHECKING

MODEL CHECKING: MAIN INGREDIENTS

- Temporal logic
  - To express a formal specification/property
- Transition systems
  - To describe an abstract model of a system/design
- Algorithms
  - To verify or not that an abstract model satisfies a formal specification
    - By exploring all possible execution paths

MODEL CHECKING: THE PROBLEM

- Temporal logic
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- Transition systems
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- Algorithms
  - To verify or not that an abstract **model satisfies** a formal **specification**
    - By exploring all possible execution paths

$$M \models S$$

MODEL CHECKING: PROBLEM VARIANTS

- There are many different **variants** according to different (classes of)
  - system properties
  - system models

M |= S

- Need to develop scalable algorithms to check for satisfaction

MODEL CHECKING: PROBLEM VARIANTS
(CONT'D)

$M \models S$

- System models: design choices
  - State-based vs Event-based
  - Interleaving vs True Concurrency
  - Synchronous vs Asynchronous interaction
  - …

MODEL CHECKING: PROBLEM VARIANTS
(CONT'D)

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Choices in the literature yield
- CSP
- Petri nets
- I/O Automata
- Reactive modules
- **Logical formulae**
- …

MODEL CHECKING: PROBLEM VARIANTS
(CONT'D)

$M \models S$

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  Motivation: **ease of modeling**

Choices in the literature yield
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MODEL CHECKING: PROBLEM VARIANTS
(CONT'D)

$$M \models S$$

- System properties: design choices
  - Automata vs Logic
  - Linear vs Branching
  - **Safety vs Liveness**
  - Propositional vs First-Order

- **Safety** = something *bad* will *never* happen
- **Liveness** = something *good* will *eventually* happen
  - Don't know when

MODEL CHECKING: PROBLEM VARIANTS
(CONT'D)

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  - Propos

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  - Don't know when

- **Safety** =
witness

- **Liveness** = properties whose violation has no finite witness

MODEL CHECKING IN SHORT

- Initially, MC was for finite state systems
  - Widely adopted in the HW industry
  - First workable technique for automated verification

- Afterwards, MC modified and extended in many different directions
  - Real-time & hybrid systems
  - SW (abstraction & refinement)
  - Petri nets
  - Infinite-state systems
    - Parametric and parametrized systems
    - Distributed systems
  - MC = Algorithm (automated) verification

- **Symbolic methods** increasingly adopted

Safety Problems

(informal description - very basic schema)

- We call I the set of initial states, U the set of undesired states, τ the transition relation (the system moves from a state s to any state s' such that the condition $\tau(s, s')$ is satisfied).
- We iteratively compute the preimage of U applying backward τ

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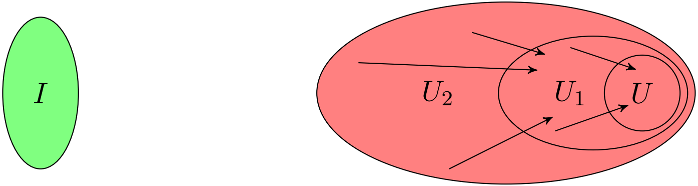

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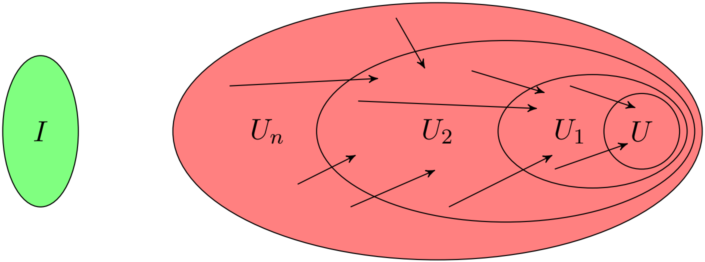

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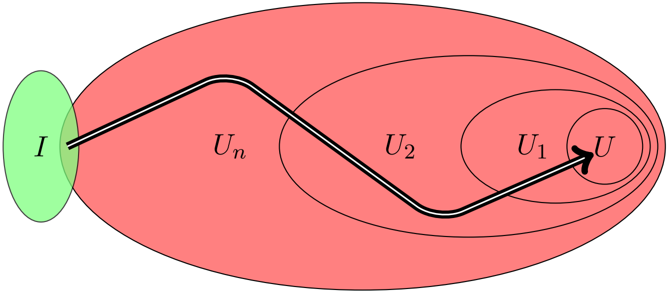

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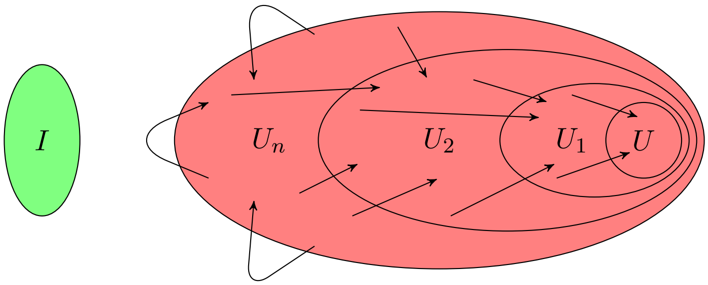
- We iteratively compute the preimage of U applying backward τ
- ... until we find an intersection with the set of initial states...
- ... or a (global) fix-point.



In the former case the system contains a bug.

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In the latter case, a safety certification is reached (notice that the complement of the ‘red’ region is an invariant for the system - i.e. it is a set of states encompassing initial states and closed under the application of transitions).

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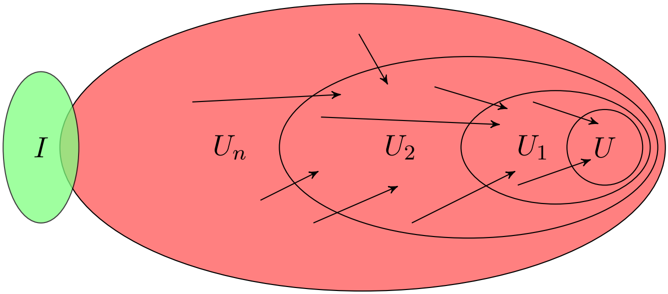
Finally, we need the appropriate technology to 'discharge' such proof obbligations. This technology is supplied by the so-called SMT-solvers.

Model checking

Backward reachability

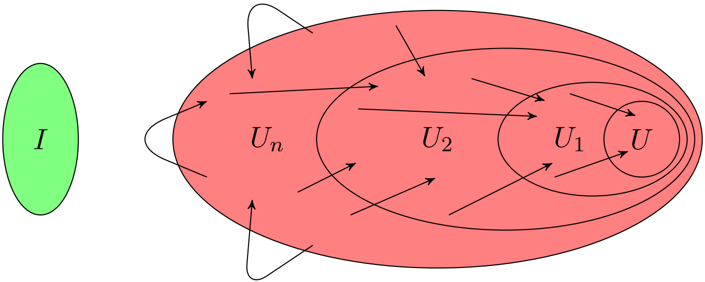
Reduce intersection and fix-point test to satisfiability problems:

- Intersection test: is $I \wedge U_n$ satisfiable?



Reduce intersection and fix-point test to satisfiability problems:

- Intersection test: is $I \wedge U_n$ satisfiable?
- Fix-point test: is $U_{n+1} \rightarrow U_n$ valid?
- ...or equivalently: is $U_{n+1} \wedge \neg U_n$ unsatisfiable?



Refinements

- In fact, the above reachability analysis via backward (or, dually, forward) search is very rough; there are termination problems (unavoidable because problems are mostly undecidable).

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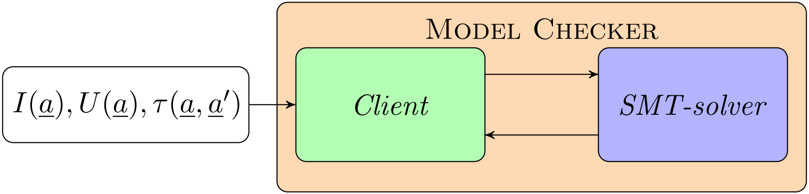
- Refinements are guided by counterexamples (i.e. by the analysis of spurious traces arising).
- There are plenty of techniques (we won't analyze here): acceleration, predicate abstraction, interpolation, property directed reachability,...
- In all cases, the model checker needs to interact with a solver discharging proof obbligations.

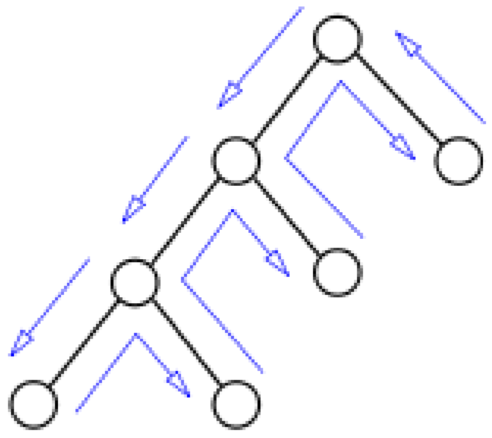
Model Checkers

Architecture

- **client** - Reachability analysis via generation of proof obbligations
- **server** - SMT-solver: decides the (un)satisfiability of proof obbligations.



SAT



- SAT problem
  - Is there an assignment that makes a given formula true?
  - Assignment to **Boolean variables**
- First NP-complete problem [Cook theorem, 1971]
- In practice, state-of-the-art SAT solvers can often solve problems problems with **millions of variables/constrai**
- Limited input language
  - Propositional logic
  - Difficulties in modeling

Extension of Davis-Putnam-Loveland-Logemann (DPPL) algorithm

SAT COMMUNITY

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satassociation.org

SAT Association

THE SAT ASSOCIATION

DPLL, CDCL, SLS, GB, SMT, BDD, AIG, MAX-SAT, Equiv Check, Model Check, more ...

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- satisfiability competition

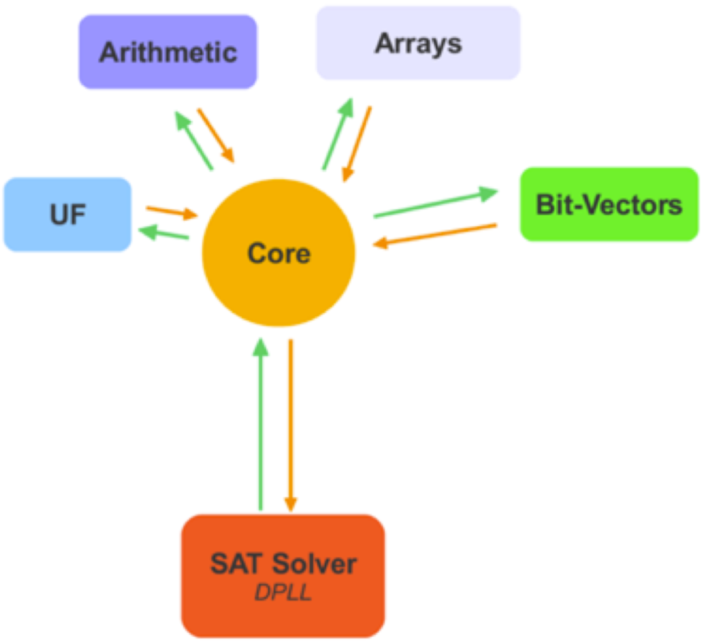
- reference
- satlive!
- smtlib
- qbflib

2016 SAT conference, Bordeaux, France

Purpose

The aim of the Association is to promote science and research, in particular with regard to the Satisfiability Problem and related areas such as Formal Verification and other applications of SAT, Proof Complexity, Serial and Parallel SAT Solvers, Satisfiability Modulo Theories, Quantified Boolean Formulas, SAT Algorithms, MAX-SAT, MUS Extraction, and SAT Encodings. This is realized by overseeing the organization and location of the series of annual conferences known as the *International Conference on the Theory and Applications of Satisfiability Testing*, promoting research in the design and analysis of algorithms for Satisfiability that should significantly impact one or more practical applications, publishing the online version of the *Journal on Satisfiability, Boolean Modeling, and Computation* (known as JSAT), and representing the SAT community in other scientific forums.

SMT

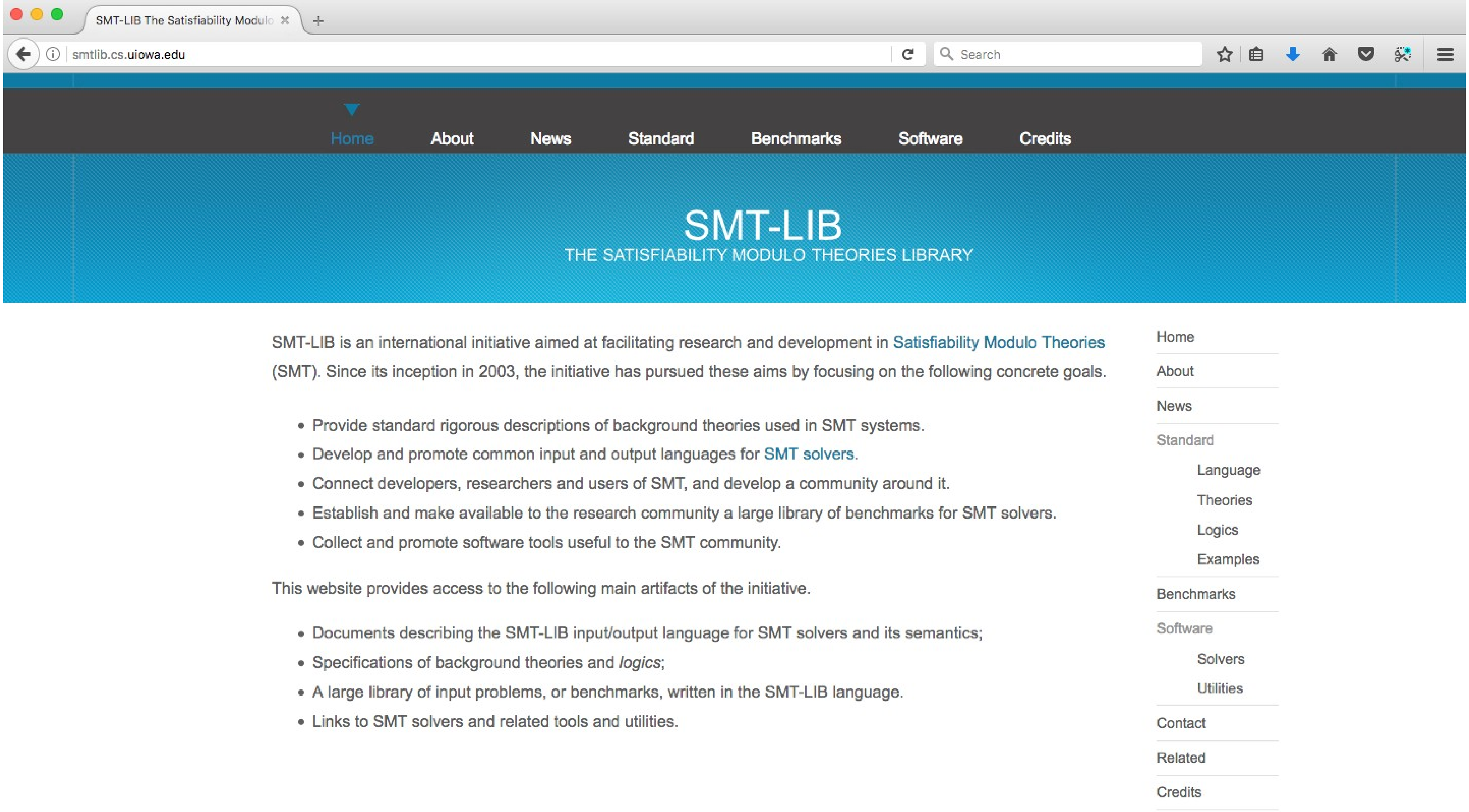


- SMT problem
  - Is there an assignment that makes a given formula true?
  - Assignment to **First-order variables**

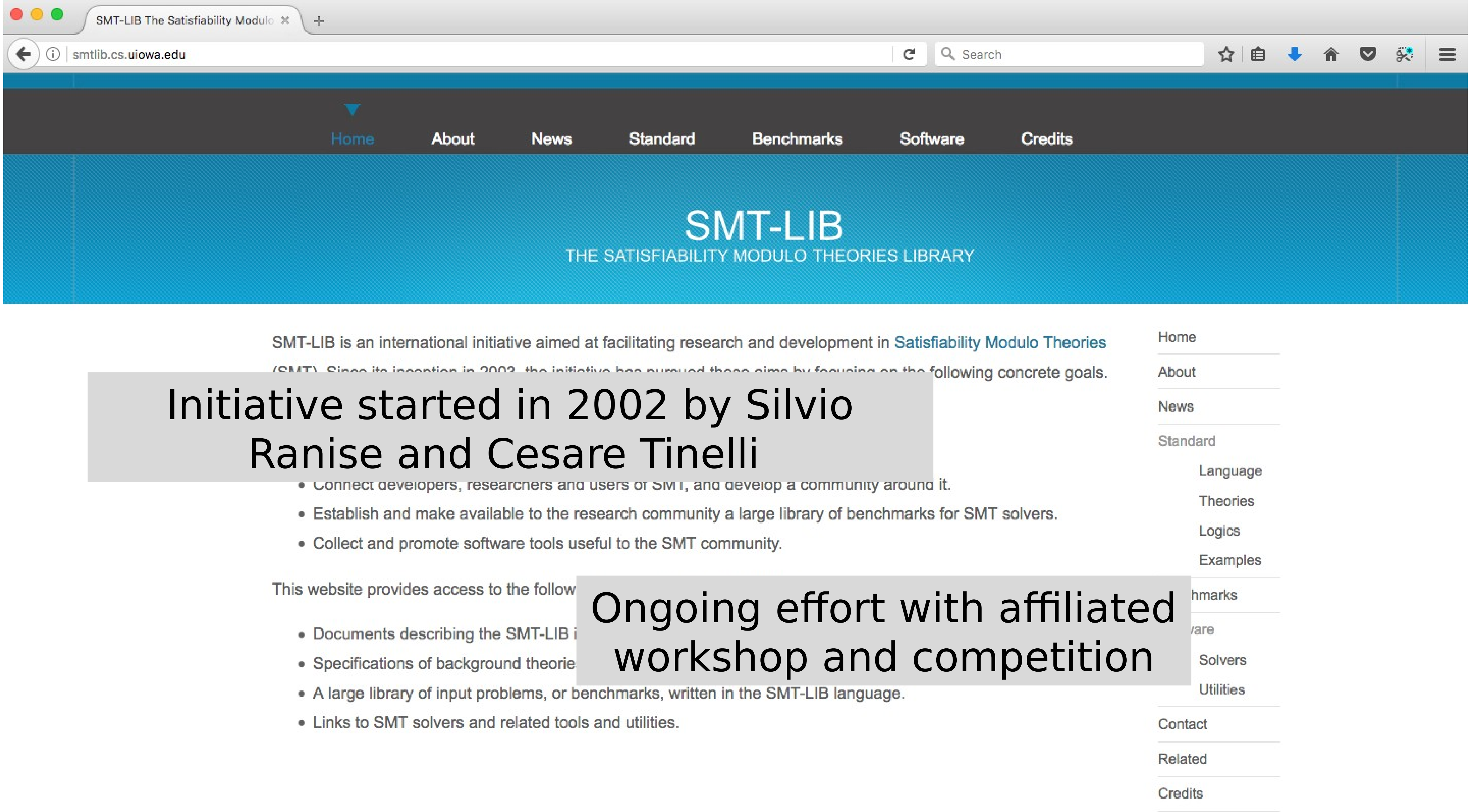
- NP-hard problem
- In practice, state-of-the-art SMT solvers can often solve problems with **millions of variables/constraint**
  - Typically formulae are quantifier-free, although…
  - ... recently there have been advances to cope with controlled quantification
- Richer input language
  - First-order logic
  - Much easier to specify models and properties (in particular of SW systems)

Lazy SMT solver architecture combining DPLL with theory solvers

SMT COMMUNITY



SMT COMMUNITY



Initiative started in 2002 by Silvio Ranise and Cesare Tinelli

Ongoing effort with affiliated workshop and competition

What an SMT Solver does?

- the core system of an SMT solver takes as input a quantifier free formula in a combined theory, like

$$(j < i \wedge a' = wr(a, j, a[j] + 1) \wedge j' = j + 1 \wedge pc' = pc) \vee$$
$$(j \geq i \wedge a' = a \wedge pc' = L)$$

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- the core system of an SMT solver takes as input a quantifier free formula in a combined theory, like

$$(j < i \wedge a' = wr(a, j, a[j] + 1) \wedge j' = j + 1 \wedge pc' = pc) \vee$$
$$(j \geq i \wedge a' = a \wedge pc' = L)$$

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- if an inconsistency is found, lemmata are learned and the control goes back to the DPLL engine for backtracking.

More Expressive Constraints

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- fragments of higher order logic also arise (e.g. cardinality constraints);
- research is very active in the area, to explore decidability limits and to determine complexities.

SMT-based Model Checking in Italy

There are various reserach groups interested in model-checking in Italy (not always, however, they follow a declarative SMT-based approach):

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- in the next slides, I shall concentrate on some contributions by my group in Milano.

MCMT

users.mat.unimi.it/users/ghilardi/mcmt/

MCMT web site

- Home
- Download
- Instructions
- Publications
- Experiments
- Related Tools
- Aknowledgments

MCMT: Model Checker Modulo Theories

Last Release: version 2.5.2 -- Last Update: 18/6/2017

MCMT is a model checker for infinite state systems based on the integration of Satisfiability Modulo Theories (SMT) solving and backward reachability. In its actual implementation, MCMT is capable of model checking invariant (safety) properties of a large class of infinite state systems called array-based systems.

Download

MCMT *is distributed "as is" without warranty of any kind; it is free for non-commercial use*. It is possible to download the executables for Linux (both 32/64 bit) and for Mac OS X together with some examples. The executables for the old versions 2.0 and 1.1.1 are still here and here.

Instructions

You can run MCMT via command line; for detailed explanations, please, have a look at the User Manual. MCMT must be linked to the SMT solver Yices.

Experiments

We run MCMT on various examples: parametrized mutual exclusion and cache coherence protocols, timed systems, imperative programs, etc. These experiments show the great flexibility of the tool. All the files for these examples are included in the distribution (in each file, a brief description of the source and the meaning of the example is supplied). Table with experimental statistics (concerning the old version 1.0) are available here. Further case studies have been analyzed:

- *Parameterized Timed Systems*: benchmarks and statistics in this area (Fischer mutual exclusion, csma, etc.) are available here;
- *Mutual exclusion, deadlock freedom and waiting time bounds for Fischer and Lynch-Shavit algorithms*: see here for full analysis, statistics and benchmarks;
- *Fault Tolerant Systems*: reliable broadcast algorithms from Chandra-

Main Publications

- *Theoretical framework*.
  S. Ghilardi, E. Nicolini, S. Ranise, and D. Zucchelli. Towards SMT Model-Checking of Array-based Systems In Proc. of IJCAR'08 (extended version).
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Technique and tool designed by Silvio Ranise and myself

Do

MC ... y kind; it is free for non ... xecutables for Linux (bo ... some examples. The exe ... ere and here.

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Cubicle

cubicle.lri.fr

Cubicle

- Overview
- Download
  - Sources
  - Binaries
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- Publications
- Experiments
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  - Description language
  - Options
  - Changelog
  - Ocamldoc
- Examples
- Contact

Overview

Cubicle is an open source model checker for verifying safety properties of array-based systems. This is a syntactically restricted class of parametrized transition systems with states represented as arrays indexed by an arbitrary number of processes. Cache coherence protocols and mutual exclusion algorithms are typical examples of such systems.

Cubicle model-checks by a symbolic backward reachability analysis on infinite sets of states represented by specific simple formulas, called cubes. Cubicle is based on ideas introduced by MCMT from which, in addition to revealing the implementation details, it differs in a more friendly input language and a concurrent architecture. Cubicle is written in OCaml. Its SMT solver is a tightly integrated, lightweight and enhanced version of Alt-Ergo; and its parallel implementation relies on the Functory library.

Download

Sources

Cubicle is distributed under the Apache licence.

You can download the sources of the latest version of Cubicle here.

Documentation and source code can be browsed online.

Binaries

- Mac OS X x86-64
- Windows (Win32 x86)

Installation instructions

Last version: 1.1.1 (13/06/2017)

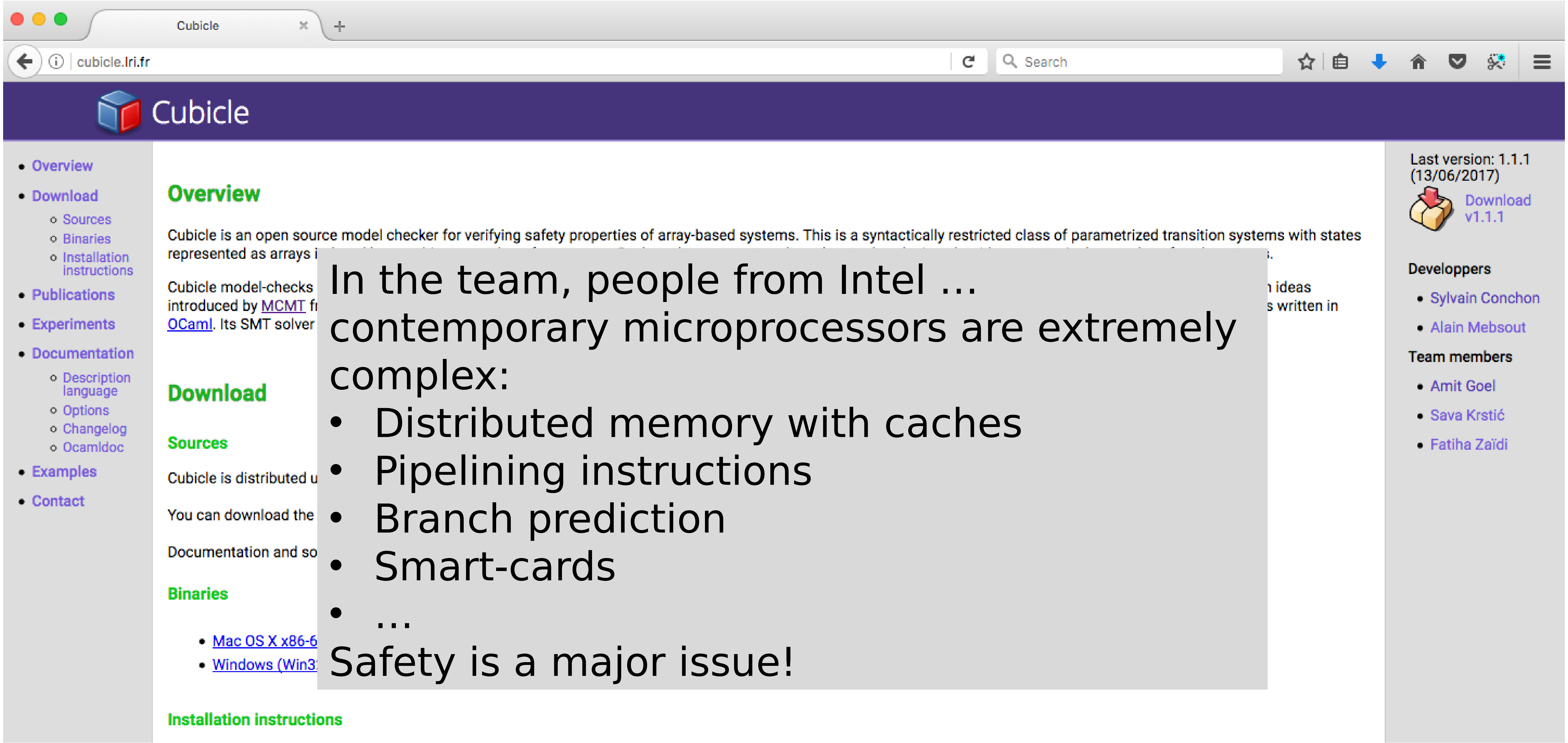
Download v1.1.1

Developpers

- Sylvain Conchon
- Alain Mebsout

Team members

- Amit Goel
- Sava Krstić
- Fatiha Zaïdi



In the team, people from Intel …

contemporary microprocessors are extremely complex:

- Distributed memory with caches
- Pipelining instructions
- Branch prediction
- Smart-cards
- …

Safety is a major issue!

Benchmarks analyzed with MCMT and related/derived/similar tools

- cache coherence and broadcast protocols;

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- $\cdots$

THANKS FOR ATTENTION !

GIORNATA DELLA FIMA

FEDERAZIONE ITALIANA DI MATEMATICA APPLICATA

Consiglio Nazionale delle Ricerche

Venerdi 27 Ottobre 2017 ore 10.00

AULA MARCONI – CNR, PIAZZALE ALDO MORO, 7 ROMA

Internal resonances in aeroelastic oscillations

Giuseppe Piccardo

Dept of Civil, Chemical and Environmental Engineering

DICCA – University of Genoa (Italy)

In cooperation with ***Prof. Angelo Luongo, University of L'Aquila***

Outline

Only a short introduction on this wide subject, related to my personal experience on the topic.
Problems that may be of interest not only for engineer but also (or more) for applied mathematics (interdisciplinary topic)

- Internal resonance
- Fluid-structure interaction problems (*wind*)
- Examples of applications
  - Linear 1:1
  - Nonlinear 1:2
- Some prospects

Internal resonances

Example of nonlinear discrete dynamical system

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} + \mathbf{n}_{2m}(\mathbf{q},\mathbf{q}) + \mathbf{n}_{3m}(\mathbf{q},\mathbf{q},\mathbf{q}) + \mathbf{n}_{2a}(\dot{\mathbf{q}},\dot{\mathbf{q}};\mu) + \mathbf{n}_{3a}(\dot{\mathbf{q}},\dot{\mathbf{q}},\dot{\mathbf{q}};\mu) = \mathbf{f}(t)$$

nl mechanical terms

nl aeroelastic terms

Internal Resonances

Nayfeh & Mook – Nonlinear Oscillations (1979)
Chapter 6 – Systems having Finite Degrees of Freedom

"In contrast with a single dof, which has only a single linear natural frequency and a single mode of motion, an *n*-dof system has *n* linear natural frequencies and *n* corresponding modes. Let us denote these frequencies by ω_1, ω_2, …, ω_n and assume that all of them are real and different from zero. An important case occurs whenever two or more are commensurable or nearly commensurable. Examples of near-commensurability are"

$$\omega_2 \approx 2\omega_1, \quad \omega_2 \approx 3\omega_1, \quad \omega_3 \approx \omega_2 \pm \omega_1,$$

$$\omega_3 \approx 2\omega_2 \pm \omega_1, \quad \omega_4 \approx \omega_3 \pm \omega_2 \pm \omega_1$$

Internal resonances

Nayfeh & Mook – Nonlinear Oscillations (1979)
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Depending on the order of the nonlinearity in the system, these commensurable relationships of frequencies can cause the corresponding modes to be strongly coupled, and an *internal resonance* is said to exist. For example, if the system has quadratic nonlinearities, then to first order an internal resonance can exist if $\omega_m \approx 2\omega_k$ or $\omega_q \approx \omega_p \pm \omega_m$. For a system with cubic nonlinearities, to first order an internal resonance can exist if $\omega_m \approx 3\omega_k$ or $\omega_q \approx 2\omega_p \pm \omega_m$ or $\omega_q \approx \omega_p \mp \omega_m \mp \omega_k$. When an internal resonance exists in a free system, energy imparted initially to one of the modes involved in the internal resonance will be continuously exchanged among all the modes involved in that internal resonance. If damping is present in the system, then the energy will be continuously reduced as it is being exchanged.

(positive)

Can internal resonance produce instability of slender structures?

Input energy is required

e.g., Fluid-Structure Interaction Problems

Blevins (2001)

FORCE ON STRUCTURE
(magnitude, coherence, time lag)

Feedback

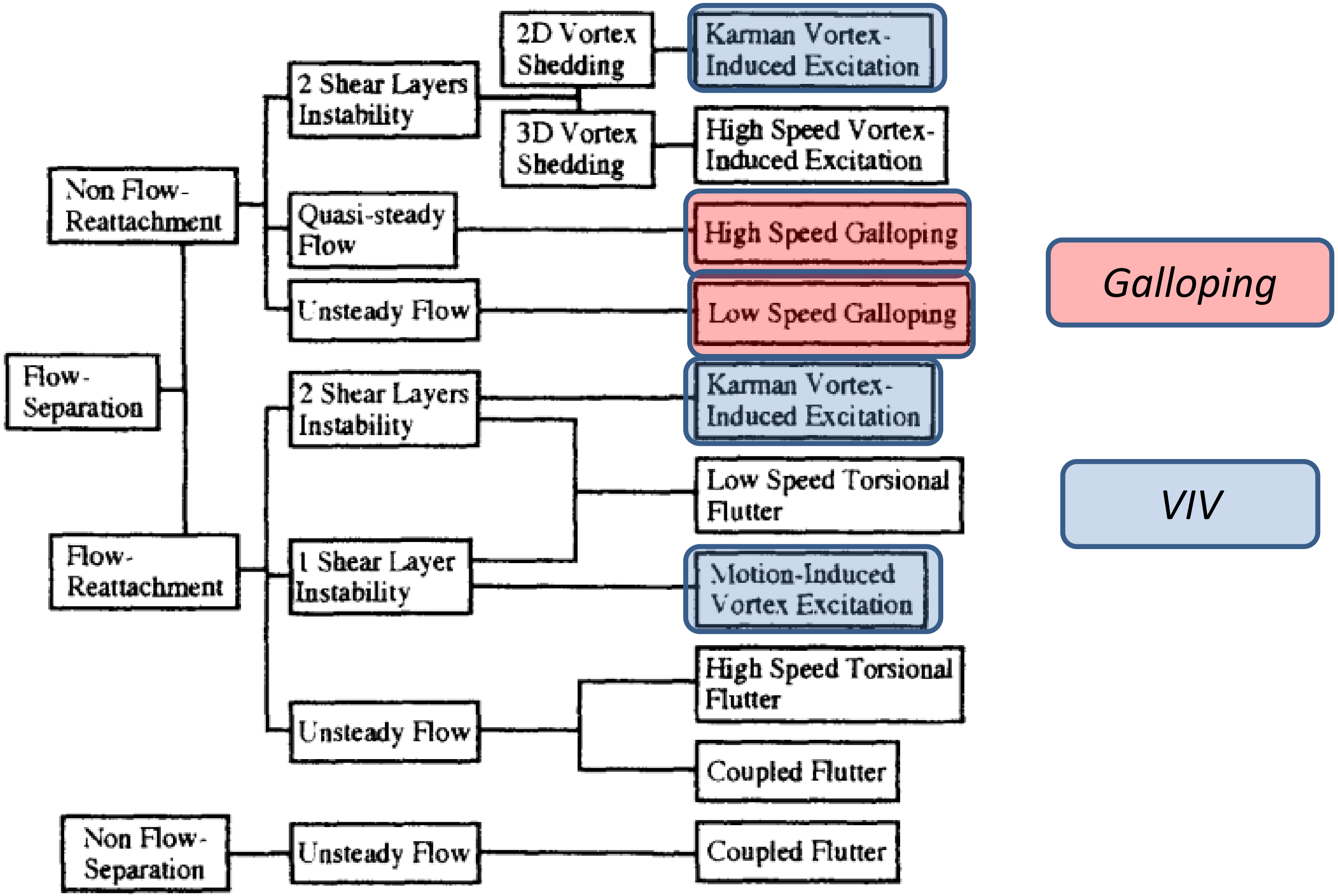
FORCE DYNAMICS
(velocity, density, e.g. turbulence and vortices in fluid)

STRUCTURAL DYNAMICS
(natural frequency, mass, damping, vibration amplitude)

LOAD/STRUCTURE BOUNDARY MOTION
(oscillation separation, local surface velocity, e.g. instantaneous angle of attack for wind)

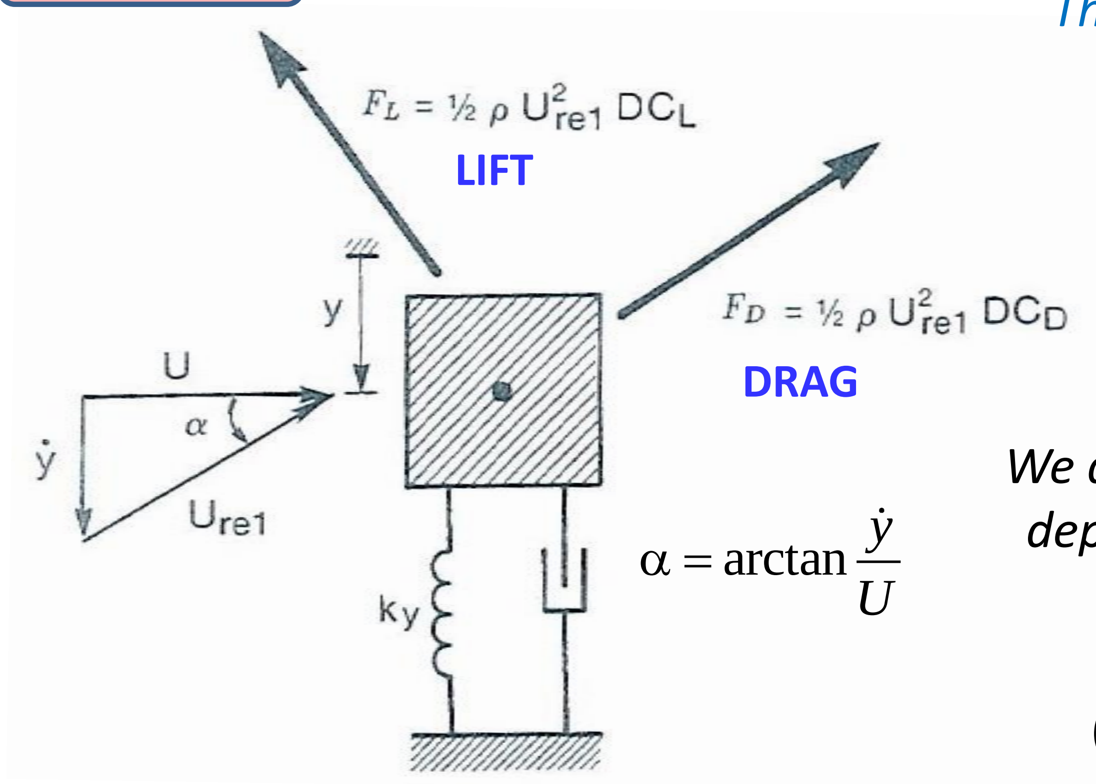
Proposal of "classification" of the aeroelastic phenomena (by Matsumoto, 1996)

Bluff-body aerodynamics



In general the physics of this phenomena is very complex, they are the subject of accurate experimental investigations

Galloping



$$\alpha = \arctan \frac{\dot{y}}{U}$$

The simplest possible model (1dof galloping model)

Flexibly supported bluff body (typically non-circular section)

We define galloping as a velocity-dependent, damping-controlled instability, giving rise to transversal oscillations (Parkinson & Smith 1964)

The **quasi-steady theory** assumes that the forces acting on a moving cylinder can be predicted adopting the expression pertinent to a fixed cylinder in which the **asymptotic flow velocity is substituted by the flow-cylinder relative velocity**

Quasi-steady modeling of aeroelastic actions

From a physical point of view this means that the forces are determined only by the instantaneous geometry and the instantaneous velocity field of the flow around the cylinder, and that any memory effect is negligible

The name Galloping seems quite appropriate because of the visual impression given when it occurs in transmission lines: typically a low-frequency high-amplitude oscillation, reminiscent of a galloping horse

Quasi-steady modeling of aeroelastic actions

This hypothesis may be satisfied if the characteristic times of the velocity fluctuations in the wake of the cylinder are much smaller than the characteristic times of the cylinder's oscillating motion:

$$\frac{1}{f_{vs}} = \frac{b}{St\,U} << \frac{1}{f_c}$$

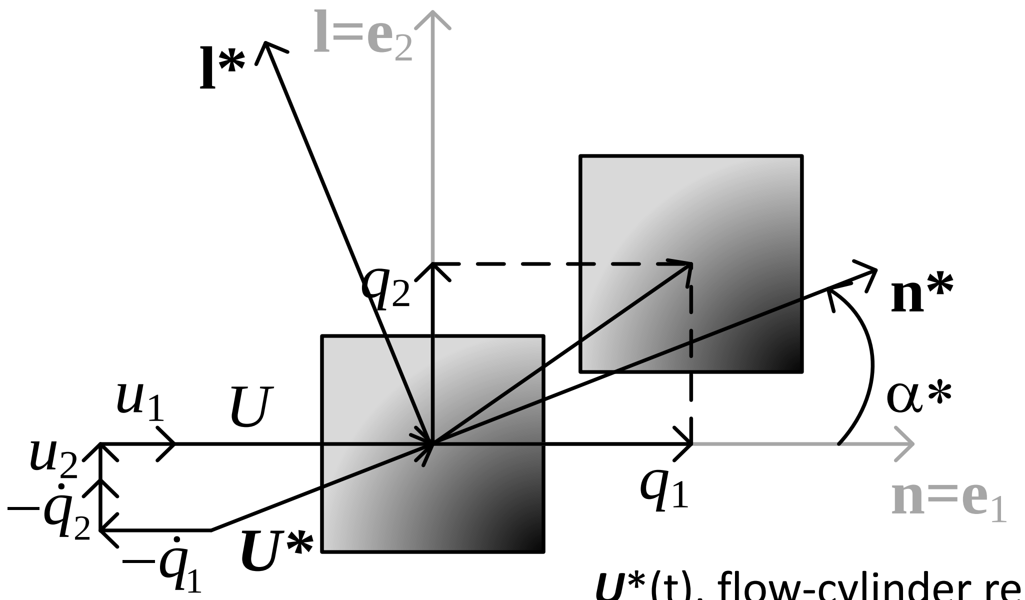
f_{vs} being the vortex-shedding frequency, *St* the Strouhal number, f_c the cylinder's oscillation frequency.

Since the *St* assumes values approximately ranging between 0.1-0.2 for the most common cross-section shapes, this requirement is often met at high reduced velocity U_r:

$$U_r = \frac{U}{f_c\,b} >> \frac{1}{St} \Rightarrow U_r > 20$$

This limit is therefore empirical and is disputed by some scientists who consider it should be much higher. Furthermore, <u>the use of quasi-steady approach is questionable when reduced velocities are not sufficiently high</u> because steady forces induced by instantaneous changes in angle of attack of the mean wind are influenced (or obscured) by unsteady vortex shedding forces acting at similar frequencies.

Quasi-steady modeling of aeroelastic actions



U*(t), flow-cylinder relative velocity

By making some simplifying assumptions (i.e. neglecting the motion in the longitudinal direction and the vertical turbulence component)

$$f_2(t) = \frac{1}{2}\rho b U^2 \left\{ \begin{aligned} & C_L + \frac{1}{U}\left[-(C_D + C_L')\dot{q}_2 + 2C_L u_1\right] + \frac{1}{U^2}\left[\frac{1}{2}(C_L + 2C_D' + C_L'')\dot{q}_2^2 + \right. \\ & \left. -(C_D + C_L')\dot{q}_2 u_1 + C_L u_1^2\right] + \frac{1}{U^3}\left[\left(-\frac{C_D}{2} - \frac{C_L'}{6} - \frac{C_D''}{2} - \frac{C_L'''}{6}\right)\dot{q}_2^3\right] \end{aligned} \right\}$$

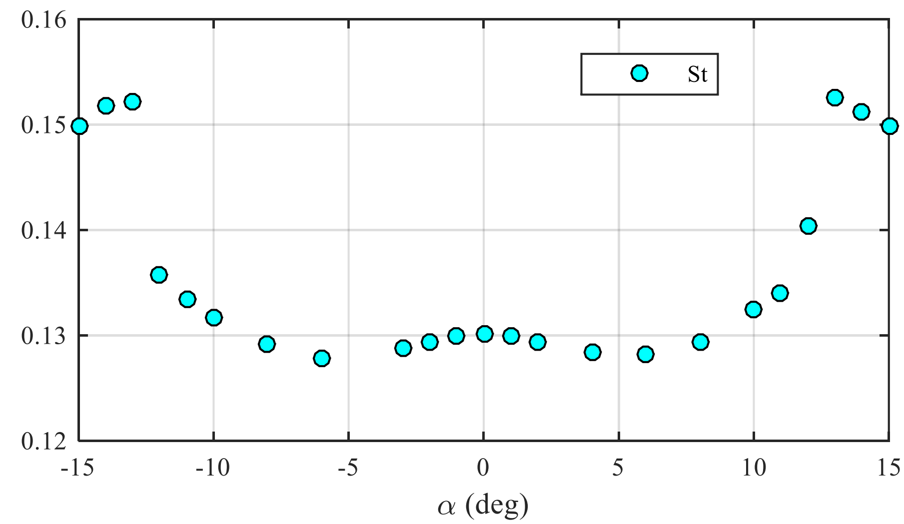
parametric excitation

external forcing

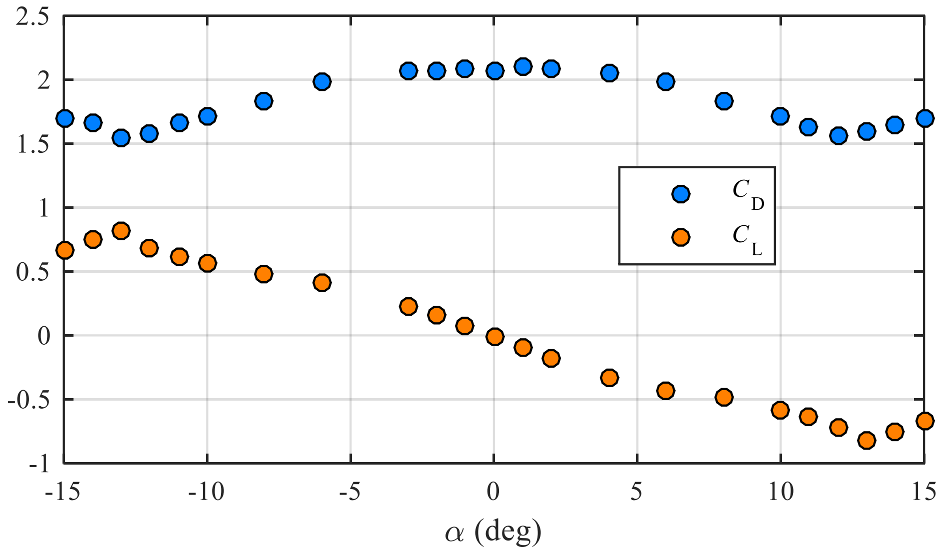
motion-induced forces

Fluid-Structure Interaction

Wind Tunnel Static Test (DICCA WT, Genoa University)

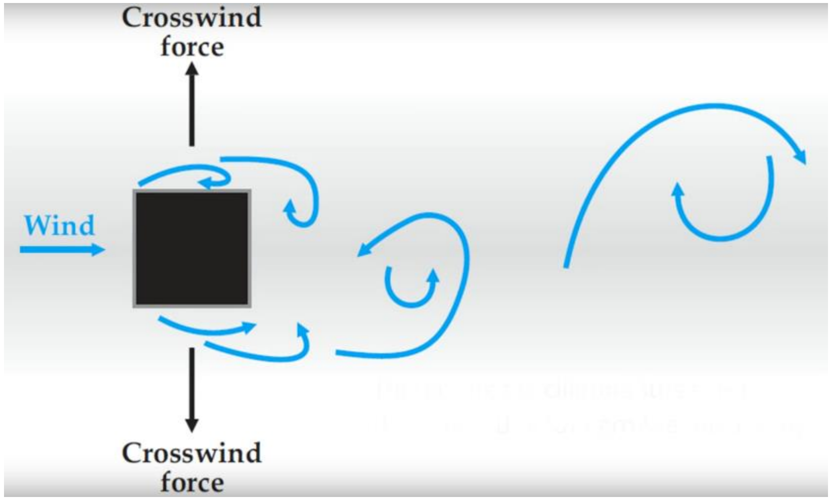


- End-plates at the extremities of the model to ensure 2D flow conditions
- St estimated by fitting the PSD function of the lift force through a Gaussian function in the neighborhood of the vs peak
- aerodynamic coefficients derived both from force measurements (force balances applied at the end of the model) and from pressure measurements (pressure taps applied to the centerline of the model)



VIV

Vortex-induced vibrations constitutes a **key element in** the **cross-wind response** of structure



Fundamental non-dimensional parameters

$$St = \frac{n_s\, b}{U}$$ Strouhal number

function of Reynolds number and roughness for circular cylinders

Scruton number $$Sc = \frac{4\pi m\xi}{\rho b^2}$$

Resonance condition in cross-wind direction, i.e. n_s=n_y

The **critical velocity** referred to the i^{th} mode can be evaluated as $$U_{cr,i} = \frac{n_{y,i} b}{St}$$

Cables, chimneys, slender structures: low critical velocities, more modes involved, fatigue problem

All **VIV models** in the literature are **empirical in nature**, trying to capture the essential features of the phenomenon, and usually involve only one structural degree-of-freedom (the crosswind one). They can be classified into **three main categories** (see, e.g., Paidoussis, Price, de Langre):

- **forced-system models**, in which the force is independent of the structural motion, and therefore only depends on time (e.g., harmonic model)

- **fluid-elastic system models**, where the force depends on the structural motion (i.e. velocity and displacement of the system; e.g., spectral model)

- **coupled system models**, in which the force depends on an additional variable related to the wake dynamics and a second equation related to the fluid oscillator is coupled with the structural motion equation (‘‘wake-oscillator models’’).

Fluid-elastic system models have been widely adopted in the literature because of their simplicity combined with their **ability to reproduce the essential features** of lock-in vibrations (i.e. the self-sustained flow instability and its self-limitation in amplitude)

Fluid-Structure Interaction

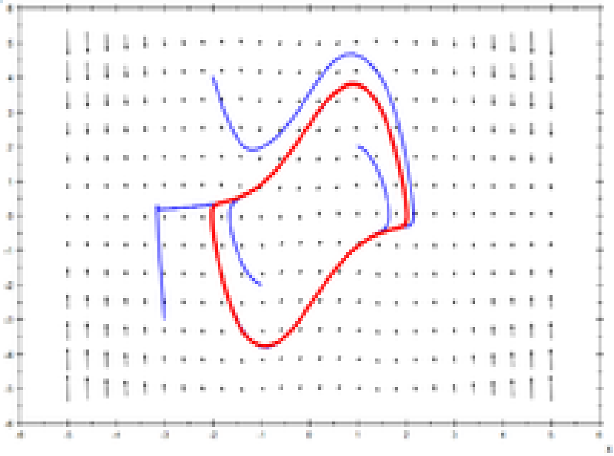
Fluid-elastic system models

From a mathematical viewpoint, the classic **van der Pol** (or, equivalently, Rayleigh) equation is able to capture these features; alternatively, the famous Ginzburg-Landau equation can be used (see Schewe, JFS 2013), whose equivalence in the description of the physical phenomenon can be roughly proved through the multiple scale method applied to Rayleigh or van der Pol oscillators

$$\frac{d^2x}{dt^2} - \underline{\mu(1-x^2)\frac{dx}{dt}} + x = 0$$

wind engineering

$$\xi_a = -\xi_s \frac{K_{a0}(k)}{Sc}\left[1-\varepsilon(k)\frac{x^2}{D^2}\right]$$



Phase portrait of the unforced vdP oscillator, showing a limit cycle and the direction field

$$\xi_{eq} = \xi_s\left[1-\frac{K_{a0}(k)}{Sc}\left(1-\frac{\sigma_x^2}{(\lambda(k)\,D)^2}\right)\right]$$

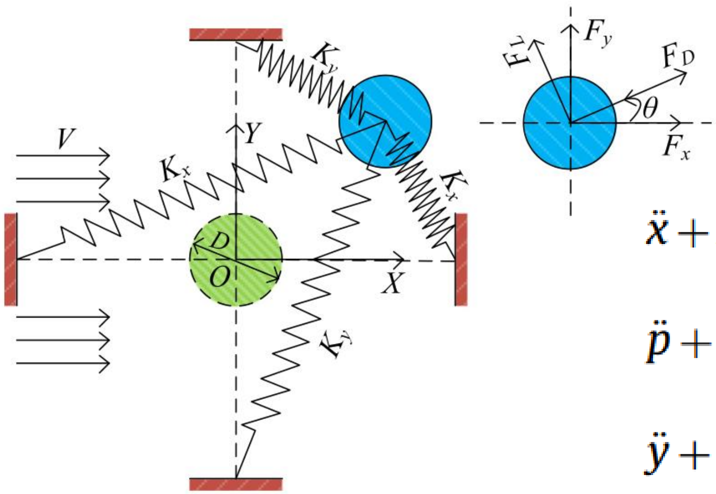
Vickery-Basu approach (1983)

Equivalent linearization of nl damping (nonlinearity now appears in statistical form)

the STD of response can be estimated based on classic random vibration theory of SDOF

Coupled-system models

Modelling of coupled cross-flow/in-line vortex-induced vibrations using double Duffing and van der Pol oscillators by Srinil & Zanganeh 2012 (Ocean Engineering)



hydrodynamic

$$\ddot{x}+\lambda_x\dot{x}+f^{*2}(x+\alpha_x x^3+\beta_x xy^2)=M_D\Omega^2 p-2\pi M_L\Omega^2(q\dot{y}/V_r),$$

$$\ddot{p}+2\varepsilon_x\Omega(p^2-1)\dot{p}+4\Omega^2 p=\Lambda_x\ddot{x},$$

$$\ddot{y}+\lambda_y\dot{y}+y+\alpha_y y^3+\beta_y yx^2=M_L\Omega^2 q+2\pi M_D\Omega^2(p\dot{y}/V_r),$$

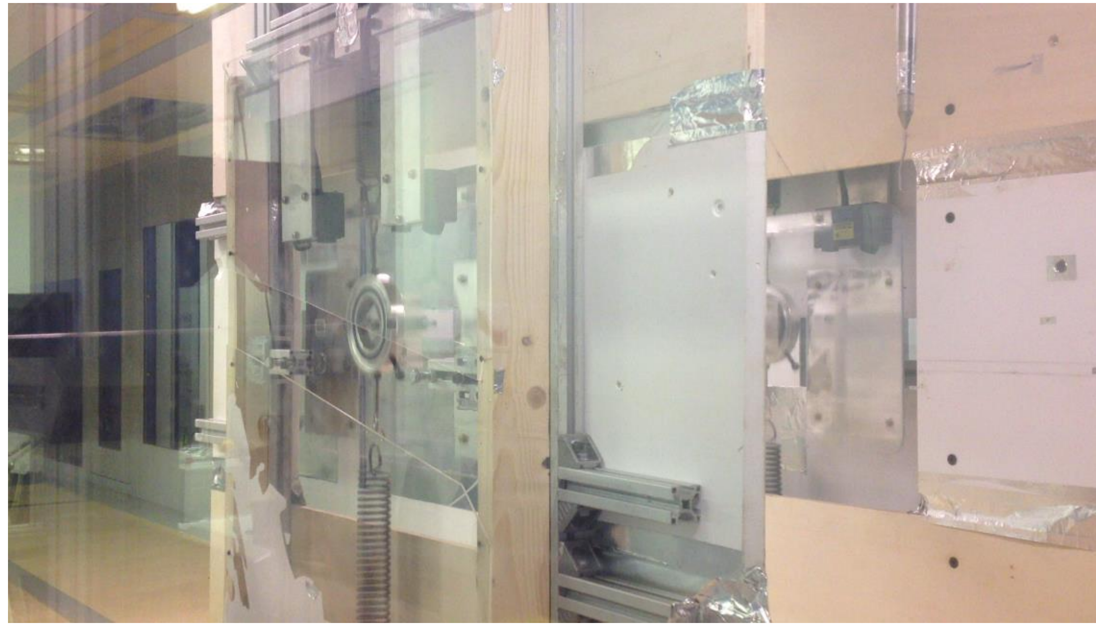
$$\ddot{q}+\varepsilon_y\Omega(q^2-1)\dot{q}+\Omega^2 q=\Lambda_y\ddot{y},$$

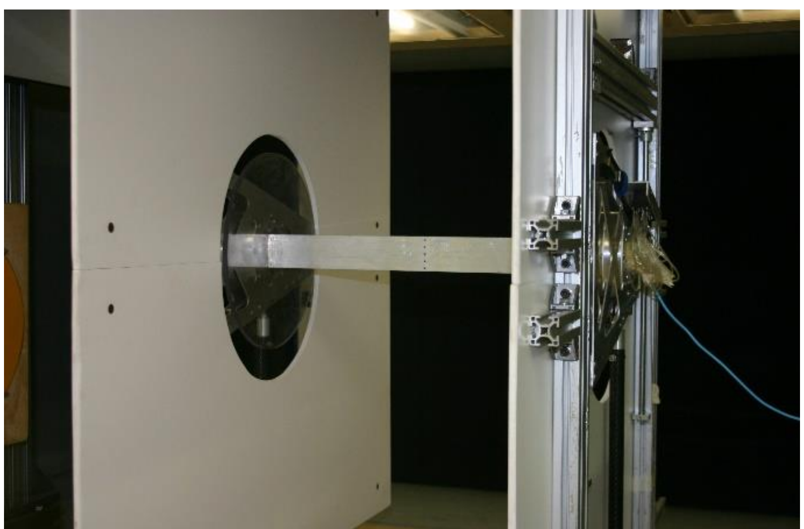
The cubic nonlinearities capture the geometrical coupling of cross-flow/in-line displacements excited by hydrodynamic lift/drag forces whereas the quadratic nonlinearities allow the wake–cylinder interactions. Some empirical coefficients are calibrated against published experimental results to establish a new generic analytical function accounting for the dependence of VIV on a physical mass and/or damping parameter.

Fluid-Structure Interaction

Wind Tunnel Aeroelastic Free/Forced Test (DICCA WT, Genoa University)

- damping ratio in the range 0.038-0.15% using the eddy currents method by means of an electromagnet
- Model displacements have been measured through laser sensors sampled at 2 kHz.





- experimental rig to test prisms moving in cross-flow direction with harmonic motion
- pressure measurements during motion at different wind speeds V = 5 – 20 m/s (V_r = 5.9 – 200 , amplitudes Y = 10%, 20% and 30%, motion frequencies 0.7 – 17.5 Hz
- motion-excited forces in terms of amplitude and phase

<u>Linear</u> instability mechanisms for coupled translational galloping (Luongo & Piccardo, JSV 2005)

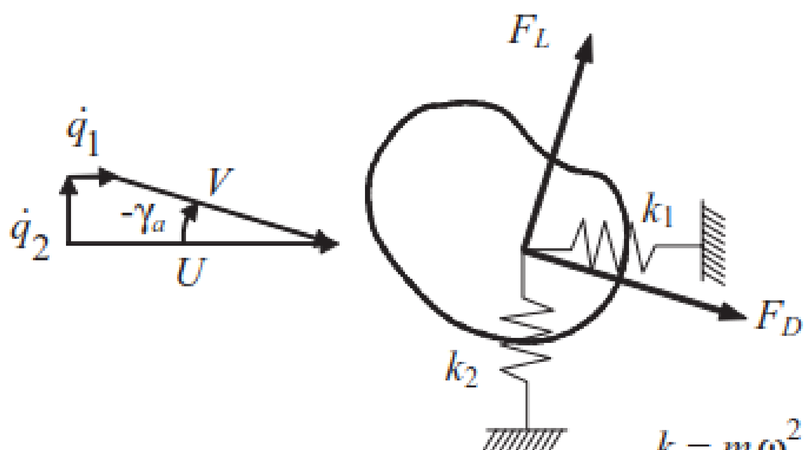
internal resonance

$$\mathbf{M}\ddot{\mathbf{q}}(t) + \mathbf{D}\dot{\mathbf{q}}(t) + \mathbf{K}\mathbf{q}(t) = 0,$$

$$\mathbf{M} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad \mathbf{D} = \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}, \quad \mathbf{K} = \begin{bmatrix} \omega^2 & 0 \\ 0 & 1 \end{bmatrix}, \quad \mathbf{q}(t) = \begin{Bmatrix} q_1(t) \\ q_2(t) \end{Bmatrix}$$

aeroelastic effects

$$\mathbf{D} = \begin{bmatrix} 2\omega\xi_s & 0 \\ 0 & 2\xi_s \end{bmatrix} + \mu \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} = \mathbf{C}_s + \mu\mathbf{C}_a$$



$$k_i = m\,\omega_i^2, \quad i = 1, 2$$

A perturbation method is applied to obtain approximate analytical expressions for the eigensolutions of the system, valid for any frequency ratio ω

$$\mathbf{D} = \varepsilon\tilde{\mathbf{D}}$$

. A perturbation parameter $\varepsilon \ll 1$ is introduced through a suitable ordering of the coefficients. Namely, it is assumed that the coefficients of the total damping matrix **D** are small of order ε

Two different cases, according to the frequency ratio ω:

(a) non-resonant solution, $|\omega - 1| > O(\varepsilon)$

(b) resonant and quasi-resonant solution, $|\omega - 1| = O(\varepsilon)$

Case (a)

$$\varepsilon^0 : \left[\mathbf{K} + \lambda_0^2 \mathbf{I}\right]\mathbf{w}_0 = 0,$$

$$\varepsilon : \left[\mathbf{K} + \lambda_0^2 \mathbf{I}\right]\mathbf{w}_1 = -2\lambda_0\lambda_1\mathbf{w}_0 - \lambda_0\mathbf{D}\mathbf{w}_0$$

Perturbation equations

Order-ε eq. is a singular non-homogenous problem. In order that it admits solution, the known-term must belong to the range of the operator (solvability, or compatibility, condition), i.e. it must be orthogonal to the null-space of the adjoint operator. Since the operator is self-adjoint, orthogonality to $\mathbf{w}_0^{(k)}$ must be enforced. From this condition, the first-order eigenvalue sensitivity $\lambda_1 = \lambda_1^{(k)}$ is drawn. Then, the first-order eigenvector sensitivity $\mathbf{w}_1 = \mathbf{w}_1^{(k)}$ is evaluated and the arbitrary constant can be removed by a suitable normalization condition

1st order non-resonant solution

$$\lambda^{(1,2)} = \pm \mathrm{i}\omega - \tfrac{1}{2}d_{11}, \quad \mathbf{w}^{(1,2)} = \left(1, \mp \frac{\mathrm{i}\omega d_{21}}{1-\omega^2}\right)^{\mathrm{T}}$$

$$\lambda^{(3,4)} = \pm \mathrm{i} - \tfrac{1}{2}d_{22}, \quad \mathbf{w}^{(3,4)} = \left(\mp \frac{\mathrm{i}d_{12}}{\omega^2 - 1}, 1\right)^{\mathrm{T}}$$

Case (b) resonant and quasi-resonant solution

$$\omega = 1 + \varepsilon\sigma,\ \sigma = O(1)$$

detuning

$$\mathbf{K} = \mathbf{K}_0 + \varepsilon\mathbf{K}_1 + O(\varepsilon^2), \quad \mathbf{D} = \mathbf{D}_0 + O(\varepsilon),$$

$$\mathbf{K}_0 = \mathbf{I}, \quad \mathbf{K}_1 = \begin{bmatrix} 2\sigma & 0 \\ 0 & 0 \end{bmatrix}, \quad \mathbf{D}_0 = 2\xi_s\mathbf{I} + \mu\mathbf{C}_a$$

Perturbation equations

$$\varepsilon^0 : \left[\mathbf{I} + \lambda_0^2\mathbf{I}\right]\mathbf{w}_0 = 0,$$

$$\varepsilon : \left[\mathbf{I} + \lambda_0^2\mathbf{I}\right]\mathbf{w}_1 = -2\lambda_0\lambda_1\mathbf{w}_0 - \mathbf{K}_1\mathbf{w}_0 - \lambda_0\mathbf{D}_0\mathbf{w}_0$$

Since $\lambda_0^{(1,2)} = \mathrm{i},\ \lambda_0^{(3,4)} = -\mathrm{i}$ are eigenvalues of double multiplicity for order-1 eq., the associated eigenvectors are indeterminate, namely:

$$\mathbf{w}_0 = \sum_{i=1}^{2} \alpha_i\mathbf{u}_i, \quad \mathbf{u}_1 = \begin{Bmatrix} 1 \\ 0 \end{Bmatrix}, \quad \mathbf{u}_2 = \begin{Bmatrix} 0 \\ 1 \end{Bmatrix}$$

In order that order-ε eq. admits solution, its right-hand term must be orthogonal to each of $\mathbf{u}_j$, i.e.:

$$\sum_{i=1}^{2}\left(2\lambda_0\lambda_1\mathbf{u}_j^{\mathrm{T}}\mathbf{u}_i + \mathbf{u}_j^{\mathrm{T}}\mathbf{K}_1\mathbf{u}_i + \lambda_0\mathbf{u}_j^{\mathrm{T}}\mathbf{D}_0\mathbf{u}_i\right)\alpha_i = 0, \quad j = 1, 2$$

It represents a new eigenvalue problem. By setting its determinant to zero, two generally different corrections of each 1st order-eigenvalue are obtained, i.e. the ε-order perturbation destroy the degeneracy.

Case (b) resonant and quasi-resonant solution

Finally, using the normalization and reabsorbing the ordering parameter ε, the following approximate eigensolutions are obtained:

$$\lambda^{(1,2)} = \mathrm{i} - \xi_s + \tfrac{1}{4}\left(-\mu\,\mathrm{tr}\,\mathbf{C}_a + 2\mathrm{i}\sigma \pm \sqrt{\mu^2\left(\mathrm{tr}^2\mathbf{C}_a - 4\det\mathbf{C}_a\right) - 4\mathrm{i}\sigma(d^0_{11} - d^0_{22}) - 4\sigma^2}\right),$$

$$\lambda^{(3,4)} = -\mathrm{i} - \xi_s + \tfrac{1}{4}\left(-\mu\,\mathrm{tr}\,\mathbf{C}_a - 2\mathrm{i}\sigma \pm \sqrt{\mu^2\left(\mathrm{tr}^2\mathbf{C}_a - 4\det\mathbf{C}_a\right) + 4\mathrm{i}\sigma(d^0_{11} - d^0_{22}) - 4\sigma^2}\right)$$

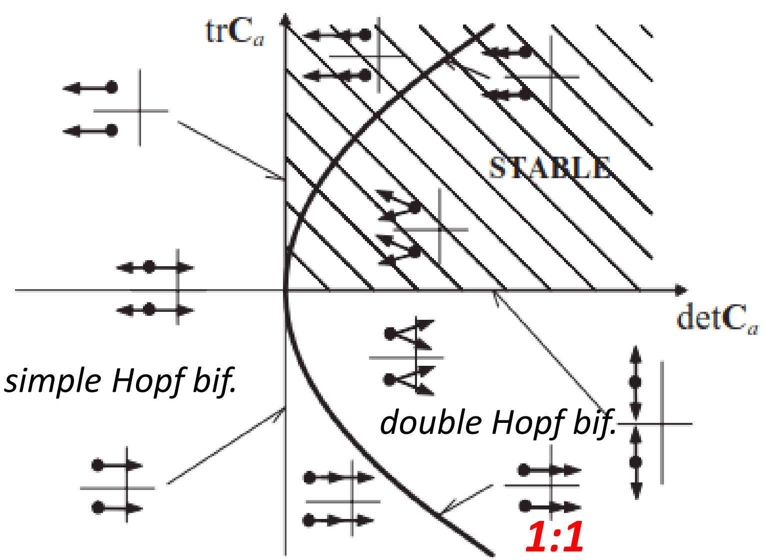
$$\mathbf{w}^{(1,2)} = \left(-\frac{\mathrm{i}d^0_{12}}{2\mathrm{i}(\lambda^{(1,2)} - \mathrm{i}) + 2\sigma + \mathrm{i}d^0_{11}},\quad 1\right)^T$$

$$\mathbf{w}^{(3,4)} = \left(\frac{\mathrm{i}d^0_{12}}{-2\mathrm{i}(\lambda^{(3,4)} + \mathrm{i}) + 2\sigma - \mathrm{i}d^0_{11}},\quad 1\right)^T$$

the use of the aerodynamic damping matrix $\mathbf{C}_a$ makes explicit the role of the dimensionless wind velocity μ

Eigenvalue paths for increasing wind velocities in the plane of the <u>aerodynamic damping matrix invariants</u>; the parabola has equation

$$\mathrm{tr}^2\mathbf{C}_a - 4\det\mathbf{C}_a = 0$$

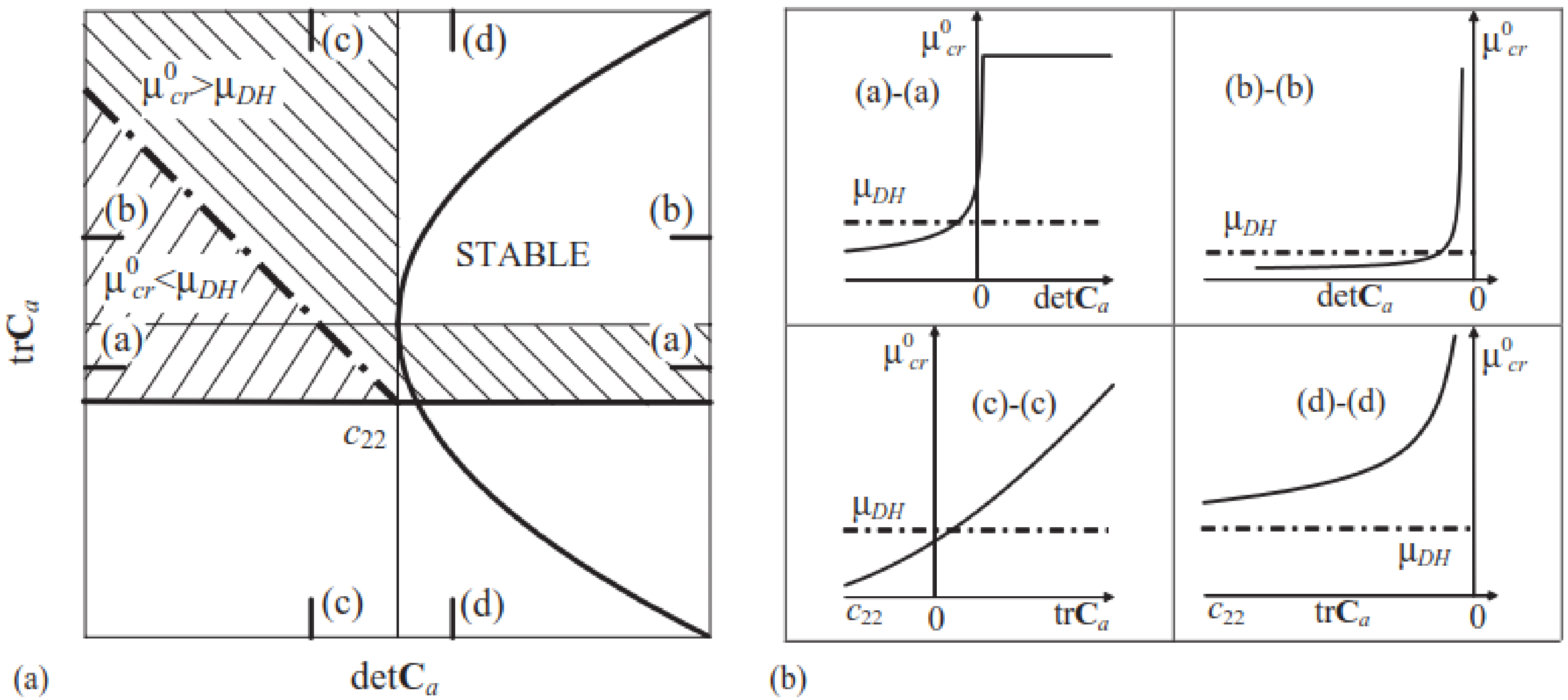


resonant solution

the lowest critical wind velocity as a function of the $\mathbf{C}_a$-invariants

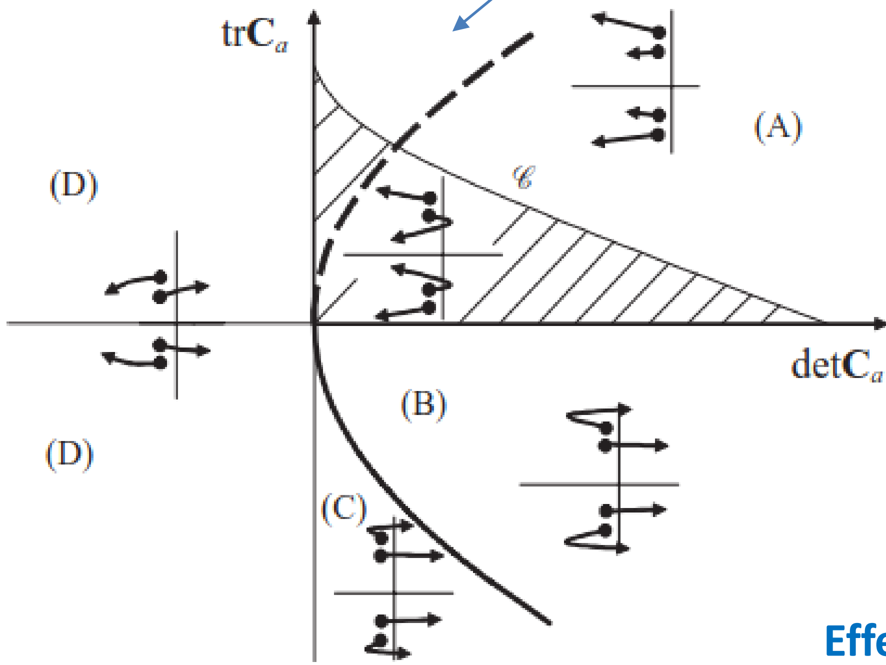
$$\mu_{\mathrm{cr}}^0 = \begin{cases} \dfrac{4\xi_s}{-\mathrm{tr}\,\mathbf{C}_a + \sqrt{\mathrm{tr}\,\mathbf{C}_a^2 - 4\det\,\mathbf{C}_a}} & \text{if } \det\,\mathbf{C}_a < 0 \text{ or } \mathrm{tr}^2\mathbf{C}_a - 4\det\,\mathbf{C}_a > 0,\ \mathrm{tr}\,\mathbf{C}_a < 0, \\ -\dfrac{4\xi_s}{\mathrm{tr}\,\mathbf{C}_a} & \text{if } \mathrm{tr}\,\mathbf{C}_a^2 - 4\det\,\mathbf{C}_a \leqslant 0,\ \mathrm{tr}\,\mathbf{C}_a < 0, \end{cases}$$

Critical wind velocity in the resonant case compared with the Den Hartog value



quasi-resonant solution

summarizes all the possible critical conditions exhibited by the quasi-resonant system

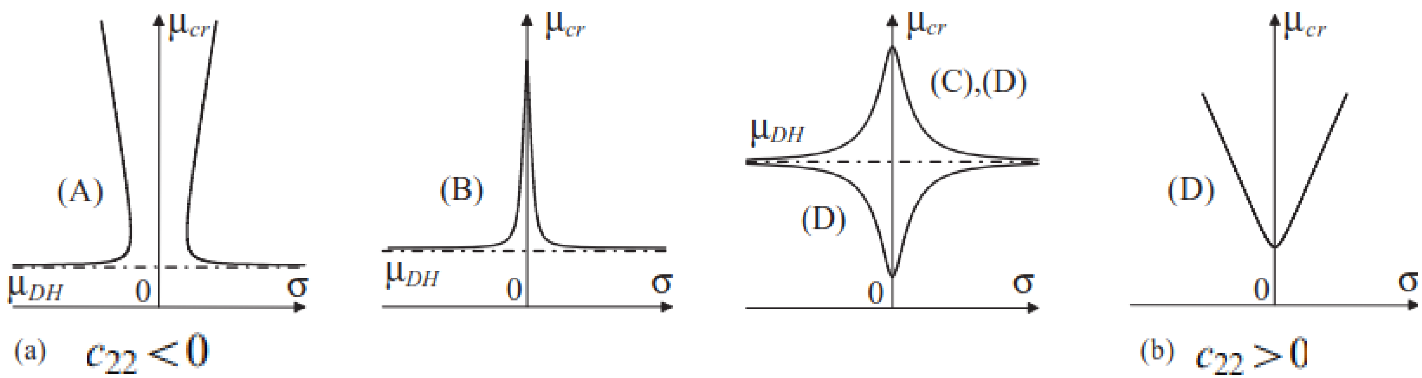


Eigenvalue paths for increasing wind velocities in the plane of the aerodynamic damping matrix invariants

parabola equation

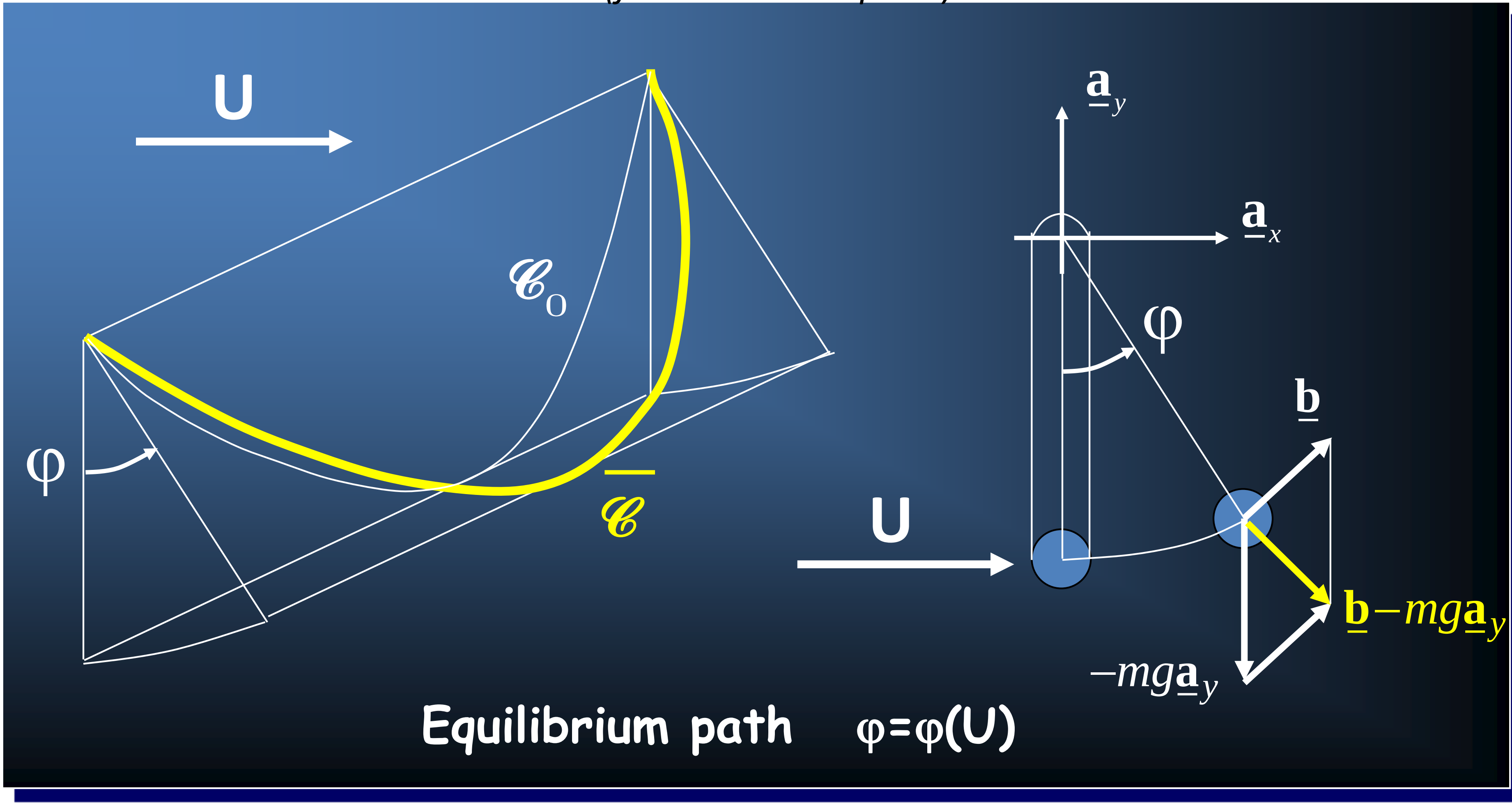
$$\mathrm{tr}^2\mathbf{C}_a - (4 + \sigma^2/\xi_s^2)\det\mathbf{C}_a = 0$$

Effect of internal resonance



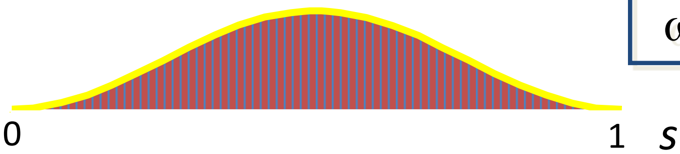
A <u>Continuous</u> Approach to the Aeroelastic Stability of Suspended Cables in 1:2 Internal Resonance
Luongo & Piccardo, JVC 2008

first symmetric in-plane frequency is double the first symmetric out-of-plane frequency (first cross-over point)



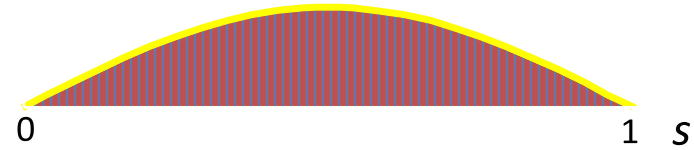
Applications – *Nonlinear Galloping*

in-plane (unstable)



$\omega_2 = 2\,\omega_1$

out-of-plane (resonant)



ω_1

- **Perturbation solution directly on the nonlinear continuum equations, avoid an 'a priori' discretization of the problem**
  - ✓ **determination of the non-trivial path related to the static equilibrium**
  - ✓ **writing the equations of motion around this equilibrium position**
  - ✓ **evaluation of the influence of the equilibrium path on aerodynamic forces**

➢ ***Equations of motion around*** $\bar{\mathscr{C}}$ *(reference cfg)*

- **small sag-span ratio (parabolic profile, curvature ≅ constant, stress ≅ constant)**
- **longitudinal inertia neglected (static condensation)**

Applications – *Nonlinear Galloping*

$$u_1'' - \Omega^2 \ddot{u}_1 = \alpha u_1'' \left[\beta \int_0^1 u_2 \mathrm{ds} - \frac{1}{2} \int_0^1 (u_1'^2 + u_2'^2) \mathrm{ds} \right] - b_1(\dot{u}_1, \dot{u}_2)$$

$$u_2'' - \alpha\beta^2 \int_0^1 u_2 \mathrm{ds} - \Omega^2 \ddot{u}_2 = \alpha u_2'' \left[\beta \int_0^1 u_2 \mathrm{ds} - \frac{1}{2} \int_0^1 (u_1'^2 + u_2'^2) \mathrm{ds} \right] - \frac{\alpha\beta}{2} \int_0^1 (u_1'^2 + u_2'^2) \mathrm{ds} - b_2(\dot{u}_1, \dot{u}_2)$$

b.c. $u_k(0)=u_k(1)=0$

$$\tilde{u}_i = \frac{u_i}{\ell}; \; \tilde{s} = \frac{s}{\ell}; \; \tilde{t} = \omega t; \; \Omega^2 = \frac{m\ell^2\omega^2}{\bar{T}}; \; \tilde{b}_i = \frac{\hat{b}_i \ell}{\bar{T}};$$

$$\alpha = \frac{EA}{\bar{T}}; \quad \beta = \frac{8d}{\ell}; \quad \mu = \frac{\rho r U}{m\omega}; \; \omega = \frac{\pi}{\ell}\sqrt{\frac{T_0}{m}}$$

quasi-steady approach

$$\underline{\mathbf{b}} = \frac{1}{2} \rho V r \left[c_d(\gamma) \underline{\mathbf{V}} + c_\ell(\gamma) \, \underline{\mathbf{a}}_3 \times \underline{\mathbf{V}} \right]$$

static torsional rotation φ

$$b_i = b_i\left(\dot{u}_1, \dot{u}_2; \varphi\right) =$$

$$= \sum_{j=1}^{2} c_{ij}(\varphi)\dot{u}_j + \cancel{\sum_{j,k=1}^{2} c_{ijk}(\varphi)\dot{u}_j\dot{u}_k} + \sum_{j,k,\ell=1}^{2} c_{ijk\ell}(\varphi)\dot{u}_j\dot{u}_k\dot{u}_\ell$$

neglected

Applications – *Nonlinear Galloping*

The equations of motion are solved through the **Multiple Scale Method**. It is well known that this method furnishes the bifurcation equations that rule the time evolution of amplitude and phase related to active modes (e.g., Luongo et al., 2003).

When it is directly applied to pde, it automatically takes into account the contribution of passive modes, through the origin of "**secondary modes**", that are responsible for the spatial alteration of oscillation shapes, induced by the presence of nonlinearities

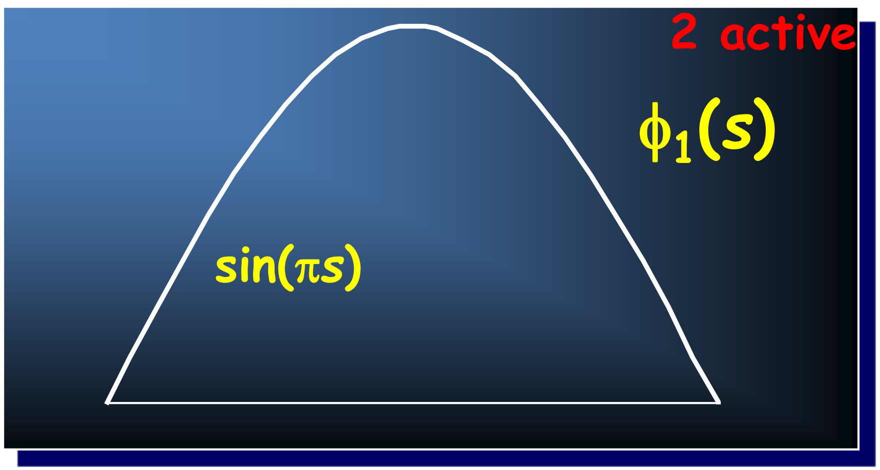
- **Asymptotic expansion**
- **Independent time scales**
- **Resonance condition**

$$\underline{\mathbf{u}} = \varepsilon \mathbf{u}_1 + \varepsilon^2 \mathbf{u}_2 + \varepsilon^3 \mathbf{u}_3, \quad \underline{\mathbf{u}} = (u_1, u_2)$$

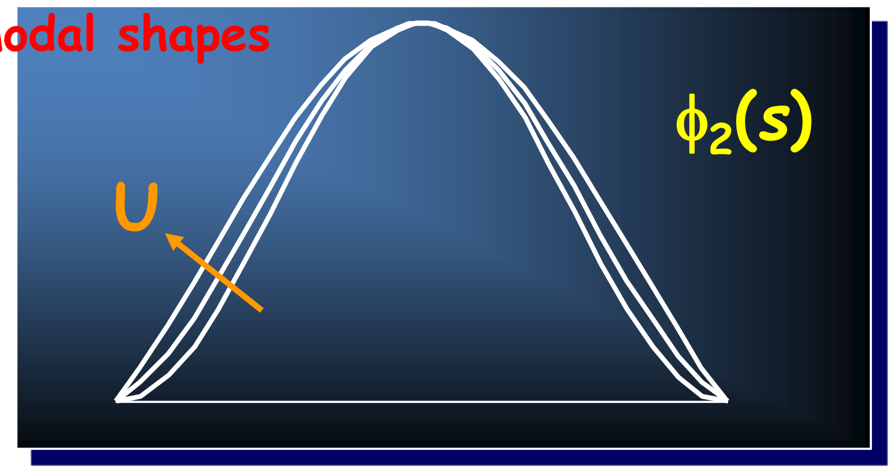
$$t_0 = t, \quad t_1 = \varepsilon t, \quad t_2 = \varepsilon^2 t, \quad ....$$

$$\omega_2 = 2\omega_1 + \varepsilon\sigma, \quad \sigma = O(1)$$

2 active modal shapes



1st mode (symmetric o-o-p)



1st mode (symmetric in-plane)

Perturbation equations

$$\mathrm{d}_k = \partial / \partial t_k$$

✓ **order ε**

$$\begin{cases} (\underline{\mathbf{L}} - \mathrm{d}_0^2)\underline{\mathbf{u}}_1 = \underline{\mathbf{0}} \\ \underline{\mathbf{B}}\underline{\mathbf{u}}_1 = \underline{\mathbf{0}} \end{cases}$$

✓ **order ε²**

$$\begin{cases} (\underline{\mathbf{L}} - \mathrm{d}_0^2)\underline{\mathbf{u}}_2 = 2\mathrm{d}_0\mathrm{d}_1\underline{\mathbf{u}}_1 + N_2(\underline{\mathbf{u}}_1, \underline{\mathbf{u}}_1) \\ \underline{\mathbf{B}}\underline{\mathbf{u}}_2 = \underline{\mathbf{0}} \end{cases}$$

✓ **order ε³**

$$\begin{cases} (\underline{\mathbf{L}} - \mathrm{d}_0^2)\underline{\mathbf{u}}_3 = 2\mathrm{d}_0\mathrm{d}_1\underline{\mathbf{u}}_2 + \mathrm{d}_1^2\underline{\mathbf{u}}_1 + 2\mathrm{d}_0\mathrm{d}_2\underline{\mathbf{u}}_1 + 2N_2(\underline{\mathbf{u}}_1, \underline{\mathbf{u}}_2) + N_3(\underline{\mathbf{u}}_1, \underline{\mathbf{u}}_1, \underline{\mathbf{u}}_1) \\ \underline{\mathbf{B}}\underline{\mathbf{u}}_3 = \underline{\mathbf{0}} \end{cases}$$

Solution of order ε

$$\underline{\mathbf{u}}_1 = \begin{pmatrix} A_1(t_1, t_2)\,\phi_1(s)\,\mathrm{e}^{\mathrm{i}\omega_1 t_0} \\ A_2(t_1, t_2)\,\phi_2(s)\,\mathrm{e}^{\mathrm{i}\omega_2 t_0} \end{pmatrix}$$

eigenfunctions of the Hamiltonian system

Solution of order ε^2

✓ **Solvability condition**

$$\int_0^{2\pi/\omega_k}\int_0^1 \left[2\mathrm{d}_0\mathrm{d}_1\underline{\mathbf{u}}_1 + N_2(\underline{\mathbf{u}}_1,\underline{\mathbf{u}}_1)\right]\phi_k(s)\,\mathrm{e}^{\mathrm{i}\omega_k t_0}\,\mathrm{d}s\,\mathrm{d}t_0 = 0 \quad (k=1,2)$$

$$\mathrm{d}_1\begin{pmatrix} A_1 \\ A_2 \end{pmatrix} = \underline{\mathbf{f}}_1(A_1, A_2)$$

Amplitude modulation on t_1

"secondary modes" describing the alteration of the spatial shape of the response, each of which is associated with a harmonic that takes part in the motion (base, sum and difference)

$$\underline{\mathbf{u}}_2 = \begin{pmatrix} 0 \\ \mathrm{i}\,A_1\,\psi_1(s) \end{pmatrix}\mathrm{e}^{\mathrm{i}\omega_1 t_0} + \begin{pmatrix} \mathrm{i}\,A_2\,\psi_2(s) \\ A_1^2\,\psi_{11}(s)\,\mathrm{e}^{-\mathrm{i}\sigma t_1} \end{pmatrix}\mathrm{e}^{\mathrm{i}\omega_2 t_0} +$$
$$+ \begin{pmatrix} A_1A_2\,\psi_{12}(s) \\ 0 \end{pmatrix}\mathrm{e}^{\mathrm{i}(\omega_1+\omega_2)t_0} + \begin{pmatrix} 0 \\ A_2^2\,\psi_{22}(s) \end{pmatrix}\mathrm{e}^{2\mathrm{i}\omega_2 t_0} +$$
$$+ \begin{pmatrix} 0 \\ A_1\bar{A}_1\,\psi_{1\bar{1}}(s) + A_2\bar{A}_2\,\psi_{2\bar{2}}(s) \end{pmatrix} + c.c.$$

The <u>shape functions</u> $\psi(s)$ are solutions of ordinary differential (linear) problems and contain the contribution of <u>*PASSIVE MODES*</u>

Applications – *Nonlinear Galloping*

Solution of order ε^3

✓ **solvability**

$$d_2\begin{pmatrix}A_1\\A_2\end{pmatrix}=\underline{\mathbf{f}}_2(A_1,A_2)$$

Amplitude modulation on t_2

Bifurcation equations

✓ **reconstitution**

$$D\begin{pmatrix}A_1\\A_2\end{pmatrix}=\varepsilon d_1\begin{pmatrix}A_1\\A_2\end{pmatrix}+\varepsilon^2 d_2\begin{pmatrix}A_1\\A_2\end{pmatrix}$$

Amplitude modulation on t

✓ **polar representation**

$$A_k=\frac{1}{2}a_k\,e^{i\vartheta_k}\qquad k=1,2$$

$$\delta=\vartheta_2-2\vartheta_1+\sigma t$$

phase difference

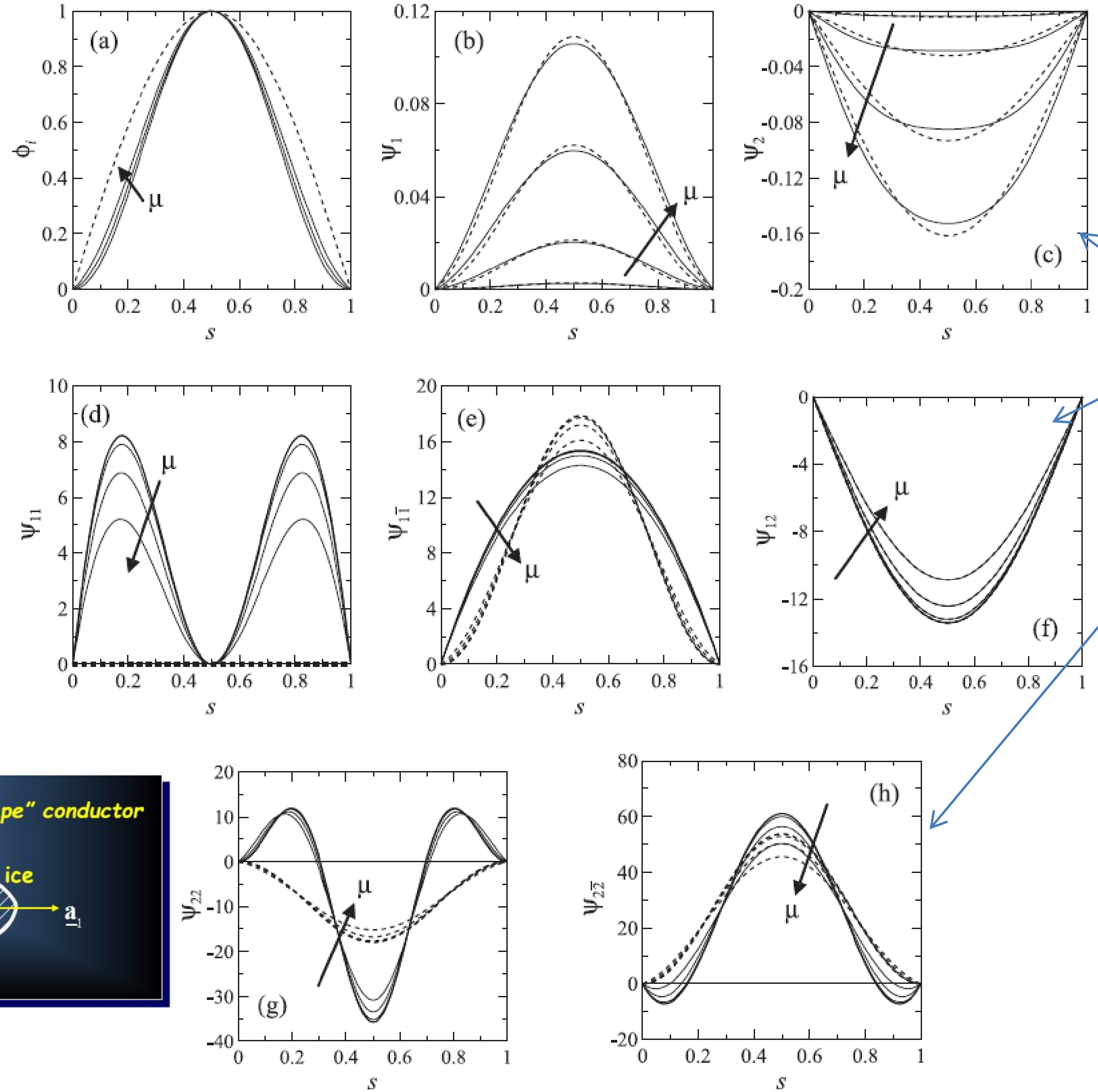
✓ **autonomous form of AME (real bifurcation eqs)**

$$\begin{cases}\dot a_1=a_1\left[\dfrac{c_{11}}{2\Omega^2}+\dfrac{1}{2}a_2(p_{21}\cos\delta-p_{22}^*\sin\delta)+\dfrac{1}{4}a_2^2p_{31}+\dfrac{1}{4}a_1^2p_{41}\right]\\[2ex] \dot a_2=a_2\dfrac{c_{22}}{2\Omega^2}+\dfrac{1}{2}a_1^2(p_{61}\cos\delta+p_{62}^*\sin\delta)+\dfrac{1}{4}a_1^2a_2p_{71}+\dfrac{1}{4}a_2^3p_{81}\\[2ex] a_1a_2\dot\delta=a_1\left[a_2(p_5-2p_1+\sigma)-a_2^2(p_{21}\sin\delta+p_{22}^*\cos\delta)+\dfrac{1}{2}a_1^2(-p_{61}\sin\delta+p_{62}^*\cos\delta)+\dfrac{1}{4}a_2^3(p_{82}-2p_{32})+\dfrac{1}{4}a_1^2a_2(p_{72}-2p_{42})\right]\end{cases}$$

Continuation and Bifurcation Software for Ordinary Differential Equation, AUTO

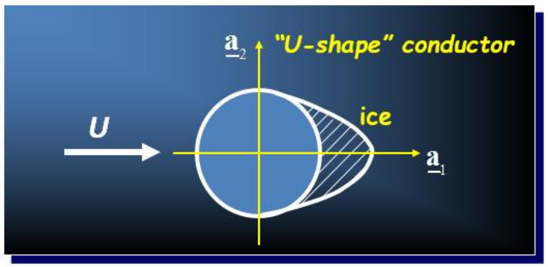
Applications – *Nonlinear Galloping*

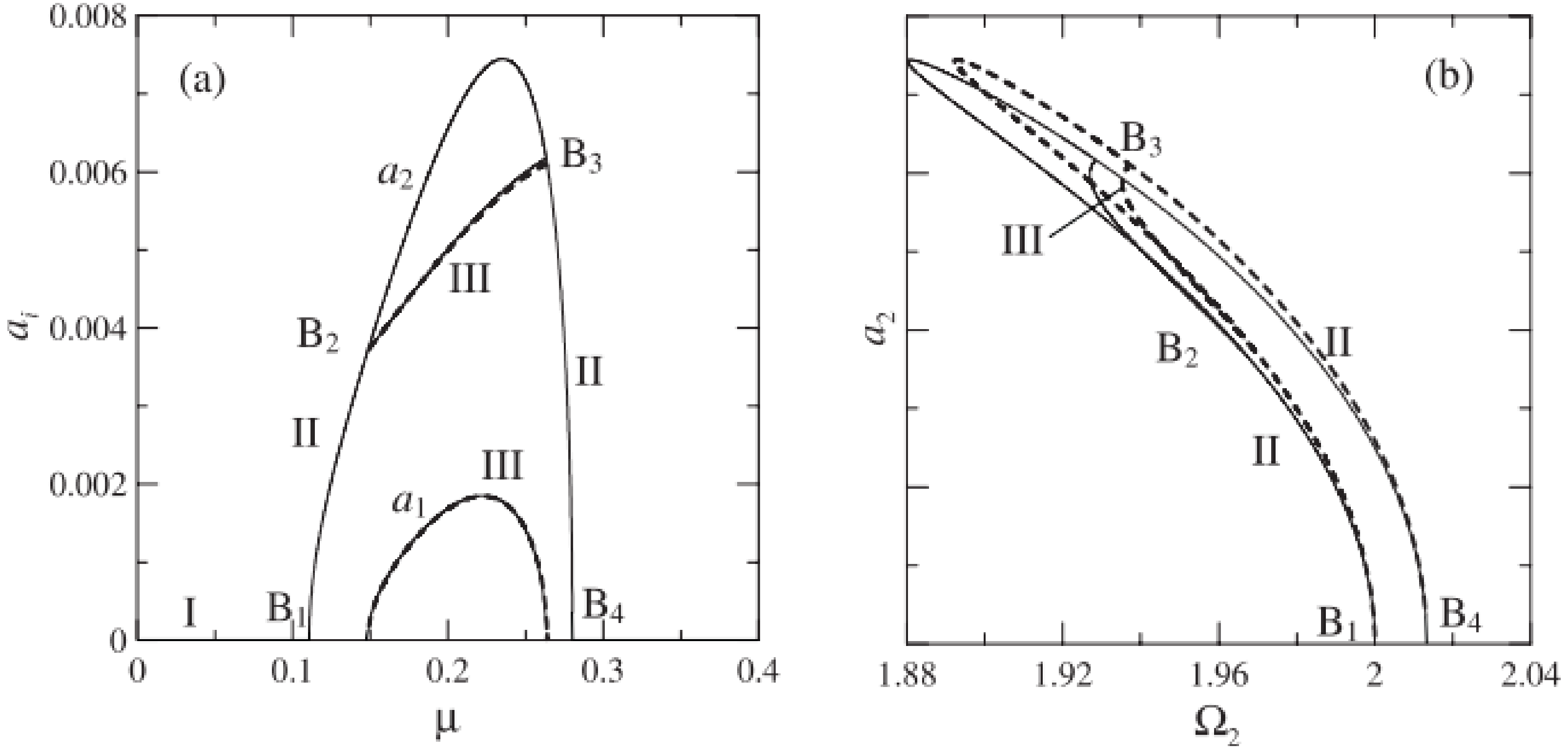
Cable primary modes



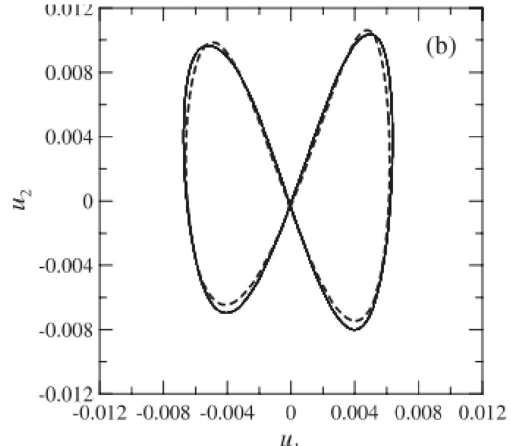
cable secondary modes

m=1.80 Kg/m
b=2.81 cm
ξ=0.44%
EA=29.7×10⁶ N
L=267.0919 m





(a) Active modal amplitudes and (b) non-linear in-plane frequency complete solution (thin lines) and active mode solution (dashed lines)



This example is marginally influenced by passive modes

Possible developments – *Nonlinear Galloping*

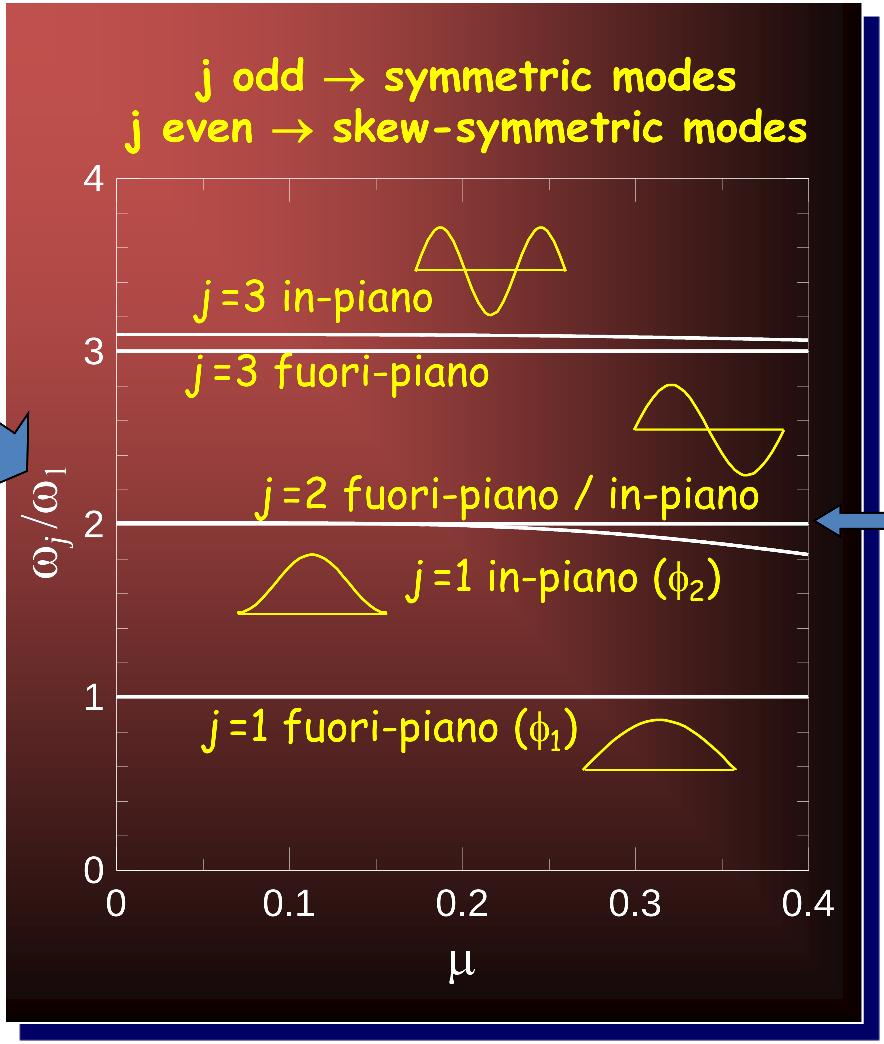
The analyzed system is, as it were, perfect; the presence of imperfections can trigger possible skew-symmetric resonant modes and the need to consider a greater number of active modes

4 active modal shapes

$$\phi_3(s)=\phi_4(s)=\sin(2\pi s)$$

only 1 detuning

$$\omega_2 = 2\omega_1 + \varepsilon\sigma, \quad \sigma = O(1)$$



Possible developments – *Nonlinear Galloping*

Solution of order ε $\Rightarrow$

$$\underline{\mathbf{u}}_1 = \begin{pmatrix} A_1(t_1,t_2)\,\phi_1(s)\,e^{i\omega_1 t} + A_3(t_1,t_2)\,\phi_3(s)\,e^{2i\omega_1 t} \\ A_2(t_1,t_2)\,\phi_2(s)\,e^{i\omega_2 t} + A_4(t_1,t_2)\,\phi_4(s)\,e^{2i\omega_1 t} \end{pmatrix}$$

- Perturbation equations of order ε^2 and ε^3 move from a number of 2 to a number of 4, in the new unknowns v and w (symmetric and skew-symmetric parts of displacements)

- It was determined the new autonomous form of AME : 7 nonlinear algebraic equations in the unknowns (a_1,a_2,a_3,a_4) e $(\gamma_1, \gamma_2, \gamma_3)$

$\Downarrow$

It has been found a path purely skew-symmetric, which presents a bifurcation point very close to that of symmetric paths

multiple bifurcation seems to actually exist

Some problems under investigation

Dry galloping in inclined cables
(Piccardo, Zulli, Luongo, Eurodyn 2017)

(inclined cables/hybrid modes, influence of internal resonances)

A warpable equivalent beam model for the analysis of tower buildings
(Luongo, Piccardo, AIMETA 2017)

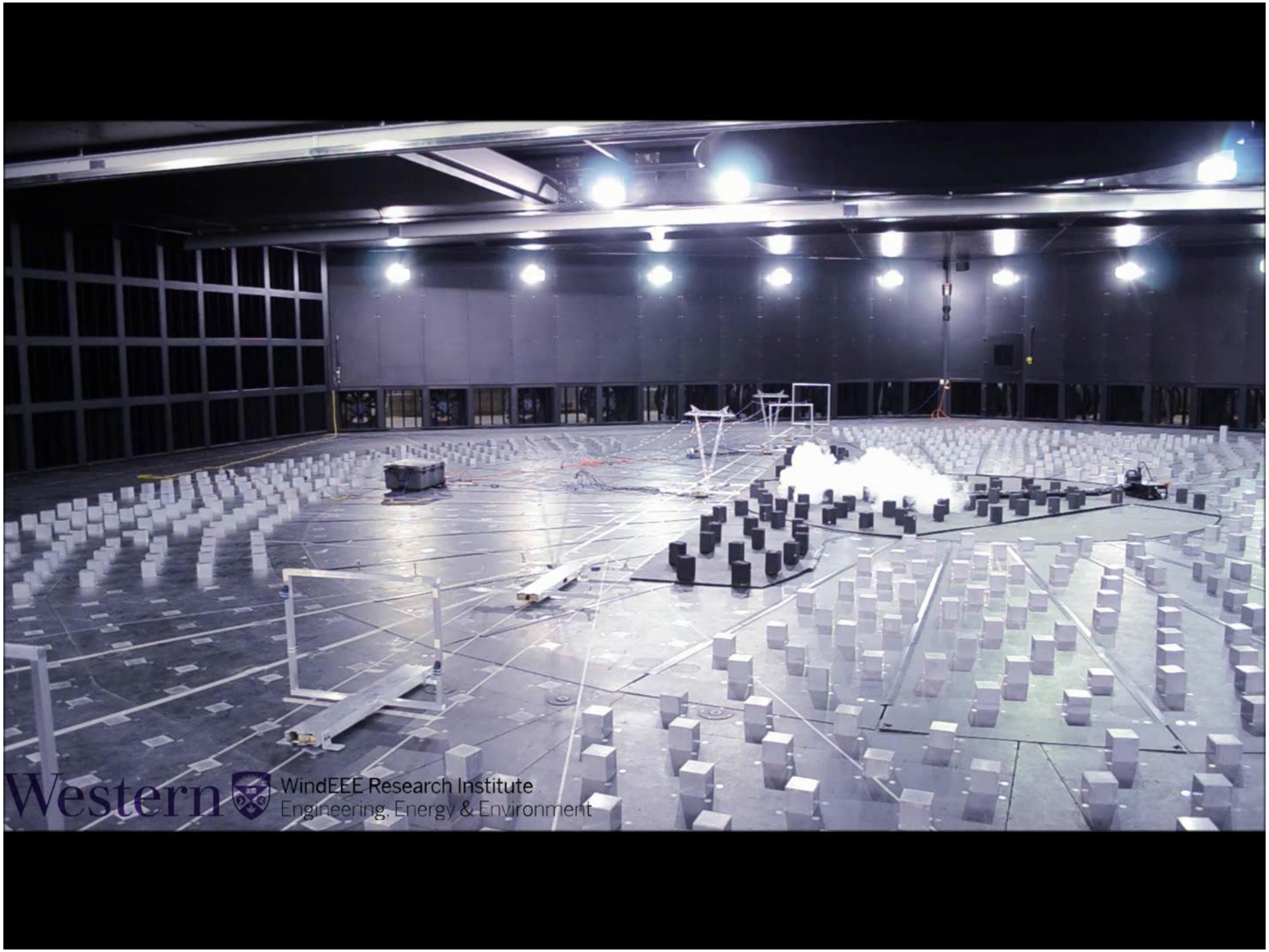
Wind- and Vortex-induced Vibrations in slender/supertall buildings
(Pagnini, Piccardo, JFS 2017; in preparation)

$T_1 \simeq 15$ s

Quasi-steady vs unsteady forces

Thunderstorm effects on structures/cables
ERC Advanced Grant (AdG) 2016 Prof. Solari – Univ. Genova
“Detection, simulation, modelling and loading of thunderstorm outflows to design wind-safer and cost-efficient structures”

Some problems under investigation



The aim of GADeS is to promote the scientific interaction between researchers operating in the fields of Solid and Structural Dynamics, Machine Dynamics and Dynamical Systems, as well as the opportunity for improving cooperation with researchers working on Identification and Control problems, **independently from the scientific sector**, thus in coherence with the AIMETA's statutory spirit.

Indeed, the **integration of researchers, who are studying particular and/or complementary problems**, appears very important since it can enlarge the range of interests of the Group. Therefore, the AIMETA GADeS Group is specifically aimed at sharing knowledge from different sectors, through the organization of workshop, mini-symposia, special sessions in AIMETA's conferences and, last but not least, the coordinated participation to Italian and European research project.

GADeS – 2017 activities

Stability and Bifurcation of Dynamical Systems: Theoretical Aspects and Applications

July 3-7, 2017, Savona, Italy

Main speakers:

Walter D'Ambrogio (Univ. L'Aquila): 'Numerical analysis of friction-induced instabilities'
Claudio Giorgi (Univ. Brescia): 'Theory of dynamical system'
Angelo Luongo (M&MoCS, Univ. L'Aquila): 'Bifurcation analysis and perturbation methods'
Michele Ciavarella (Univ. Bari): 'Thermoelastic contact instabilities'
Stefania Gatti (Univ. Modena e Reggio Emilia) 'Global study of the asymptotic behavior'
Daniele Zulli (M&MoCS, Univ. L'Aquila): 'Numerical methods in bifurcation analysis'

AIMETA 2017, Salerno (Sept 2017 – GADeS Mini-Symposium)

dedicated to the memory of Prof. Ali H. Nayfeh

45 presentations

9 sessions

≅ 1 Applied Mathematics
≅ 3 Applied (Machine) Mechanics
≅ 5 Structural Mechanics

BIG DATA and BUSINESS ANAlytics,
A Critical Overview

Giornata Della FIMA, 27 ottobre 2017, CnR Roma

Emanuele Borgonovo
Bocconi University and AMASES
Director Bachelor in Economics, Management and Computer Science
Co-Editor in Chief, European Journal of Operational Research

Università Bocconi
MILANO

Digitalization

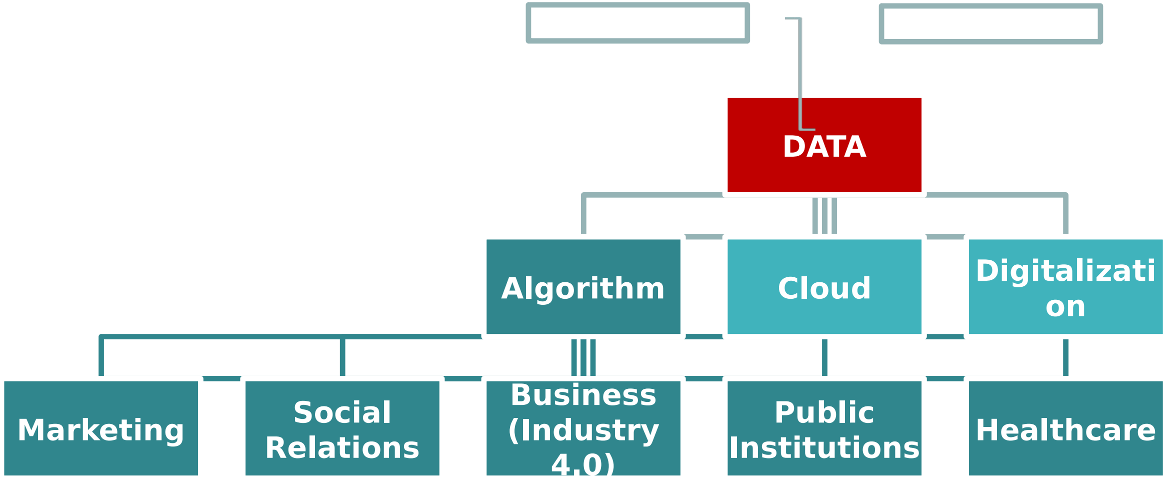
We are at the verge of the data driven economy

Globalization and increased connectivity make available to citizens, to corporations and scientists an amount of data unthinkable a few years ago

We register a large increase in the use of computers in everyday life, with new societal phenomena, entrepreneurial opportunities and new professions

Università Bocconi MILANO

Prevasiveness



Parliament

- July 2 2014
- Several players to create added value from the availability of big data
- EC document on cloud computing: big data and correlated services will reach 16,9 billion USD value in 2015, with an average growth rate of 40%, seven times higher the rate of growth of technology market

- In the UK number of big data specialists working in big firms will increase by 240% (Source: SAS report)

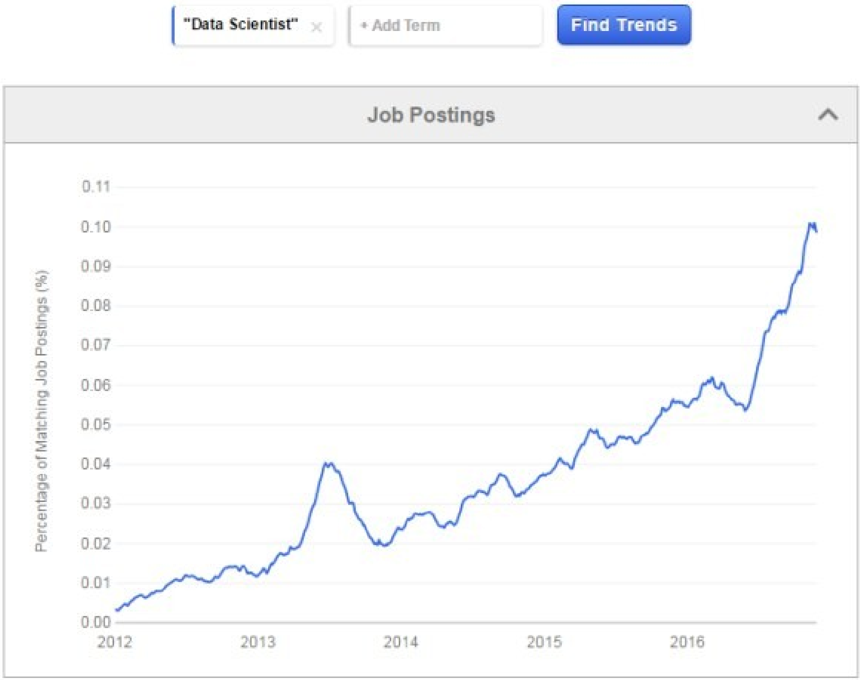
EU Document

New Professions and New Skills

D.J. Patil nominated in February 2015

first White House chief data officer

Data Science Team for the Italian Digital Agenda



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New Programs Nationally and Internationally

Bachelor Level: a few programs (Bocconi, Milan; Bologna)
MSc: 11 programs (source: MastersPortal.eu): Bologna, Genova, Milan (Bocconi, Bicocca, Cattolica, Statale), Roma (Luiss, Tor Vergata, Sapienza), Padova, Torino

Pillars

What is Big Data?

Big Data is high-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making (Source: Gartner)

- the technical skills to **gather and manage** data
- the ability to **interpret** data through the lens of economic models, thus enabling them to provide credible support to company decision making.

Computer Science

an example

Algorithms

[Click Here]

Page Rank

$$PR[A] = \frac{1-d}{N} + d\left(\sum_{k=1}^{n} \frac{PR[P_k]}{C[P_k]} \right)$$

Machine Learning: Algorithms

The dataset is divided into training and testing

The data are not prepared or labelled, the algorithm learns by similarity

Types of Algorithms… (if a list is possible…)

more

The Annals of Statistics
2007, Vol. 35, No. 6, 2313–2351
DOI: 10.1214/009053606000001523

THE DANTZIG SELECTOR: STATISTICAL ESTIMATION WHEN p IS MUCH LARGER THAN n[1]

BY EMMANUEL CANDES[2] AND TERENCE TAO[3]

California Institute of Technology and University of California, Los Angeles

$$\min_{\tilde{\beta}\in\mathbf{R}^p} \|\tilde{\beta}\|_{\ell_1} \quad \text{subject to} \quad \|X^* r\|_{\ell_\infty} \le (1+t^{-1})\sqrt{2\log p}\cdot\sigma,$$

Again, the program (DS) is convex, and can easily be recast as a linear program (LP),

$$\begin{aligned} &\min \sum_i u_i \quad \text{subject to} \quad -u \le \tilde{\beta} \le u \quad \text{and} \\ &-\lambda_p\sigma\mathbf{1} \le X^*(y - X\tilde{\beta}) \le \lambda_p\sigma\mathbf{1}, \end{aligned} \tag{1.9}$$

where the optimization variables are $u, \tilde{\beta} \in R^p$, and $\mathbf{1}$ is a p-dimensional vector of ones. Hence, our estimation procedure is computationally tractable; see Section 4.4

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Some most Recent Examples

A. Lodi, Y. Banjo, E. Frejinger (Montreal)
Using AI to help solve complex optimization problems
Helps in Mixed Integer-Linear programs
Helps in Integer programs improving branch and bound

Borgonovo, E., Lu, X. Rosasco A., Rudi A.
Fast kriging

Select your best camera
Multicriteria problem
Bayesian Approach: set a prior over a class of uncertain parameters of the algorithm
Computer Implementation

Challenges

Large Donations

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Business Impact: Industry 4.0

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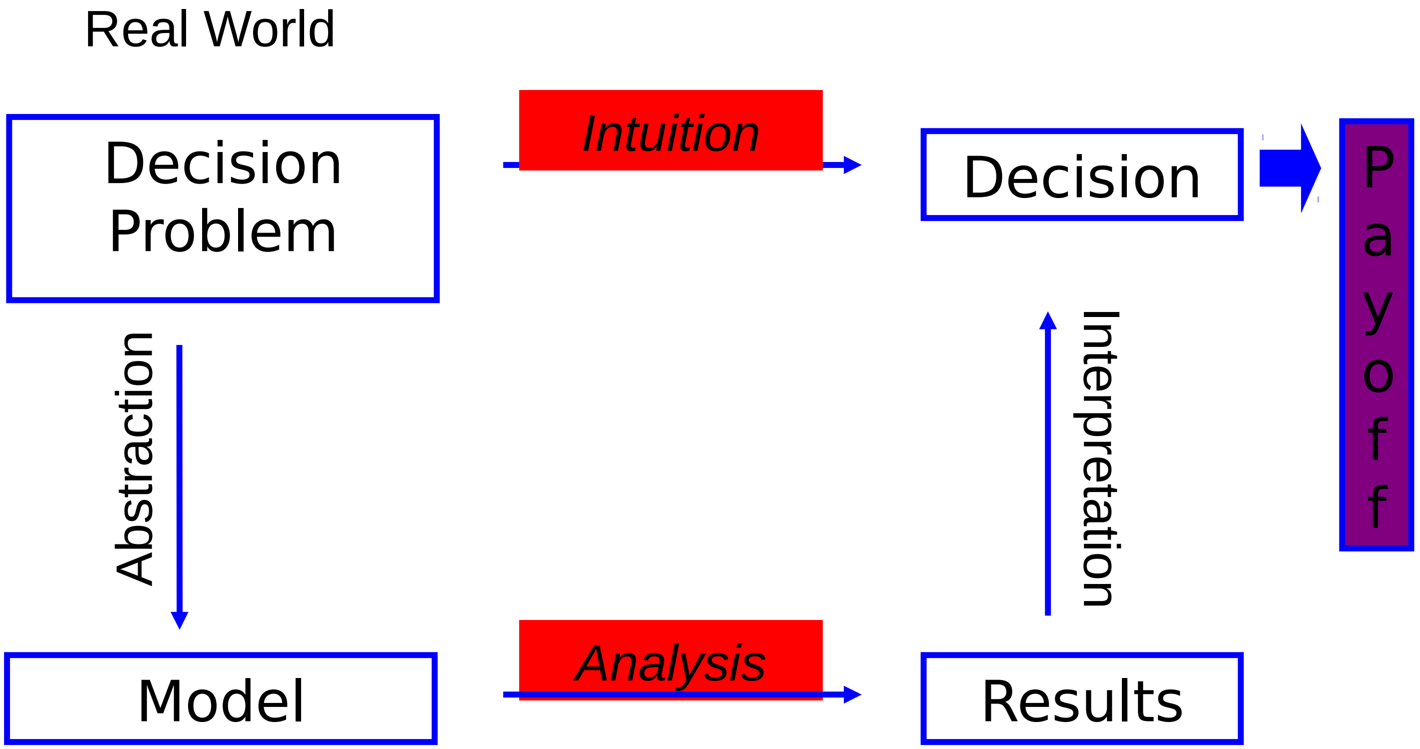
Modern Decision Making Process

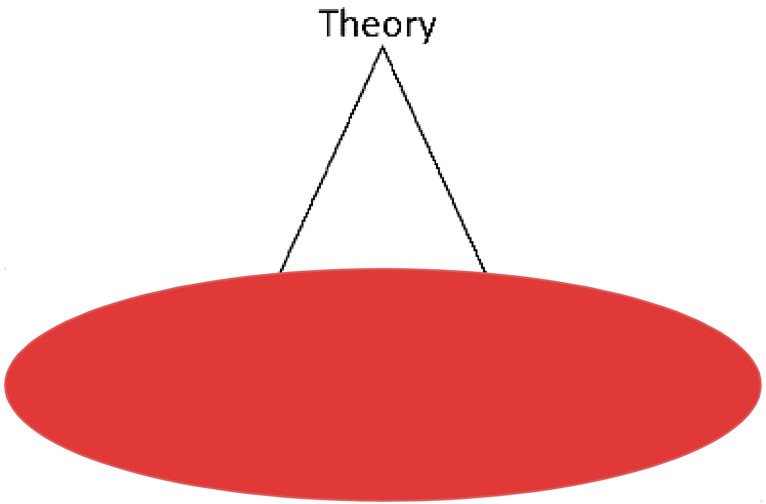


Social Impact

- New jobs for young generations?
- What about the intermediate generation?
- Need for additional education?
- How does society perceives AI?

Algorithms (models) can fail

Epistemologically, what are we doing?



Scientific Challenges

GRAZIE Per LA VOSTRA Attenzione!

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UNIVERSITÀ
DEGLI STUDI
DI MILANO

A nonlinear model for marble sulphating including surface rugosity: analytical and numerical results

Elena Bonetti
University of Milan

joint research with

Cecilia Cavaterra (University of Milan)
Maurizio Grasselli (Politecnico of Milan)
Francesco Freddi (University of Parma)
Roberto Natalini (IAC-CNR, Rome)

Workshop FIMA - Roma, 27 ottobre 2017

Conservation and restoration of historical buildings

Deterioration and damage of stones: a complex phenomenon

Mechanical actions: earthquakes, …

Chemical actions: atmospheric pollution, natural weathering, …

Mathematical models

Accademia Nazionale dei Lincei
SDSM - Stone Durability for a Sustainable Maintenance

Forecasting:
- stone durability (damages)
- impact of restoration interventions

Expensive, wasteful, complex

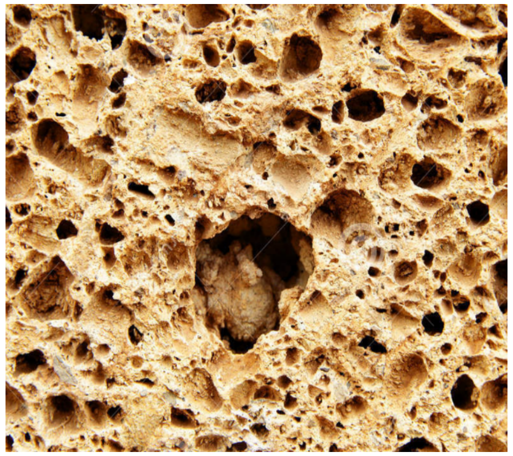
Statistical methods (Lipfert's formula), but average unsuitable values

Model:
- analytical and computational tools
- on the basis of physical evidence and data

To suggest how to schedule improved strategies of conservation and consolidation interventions on monumental stones

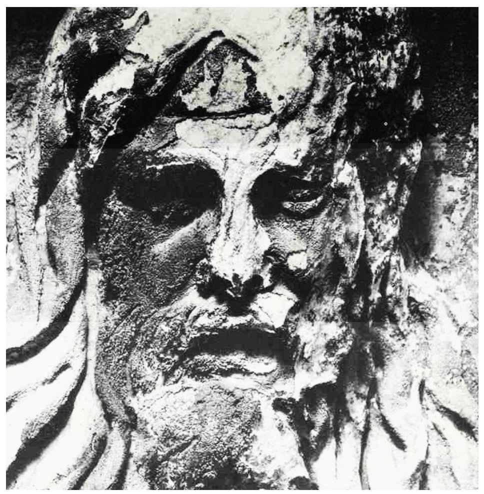
Focus more on data

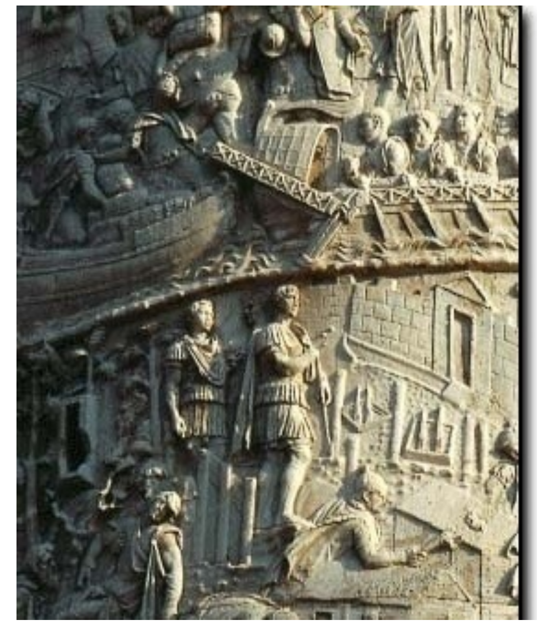
- Physico-chemical data about stones: porosity, permeability, shape and size of crystals, chemical composition, …
- Environmental data: temperature, humidity, pollution (SOx, NOx, Co2), rain, wind…
- Surface damage: rugosity, porosity, …
- 3D geometry and shape
- Mechanical properties, …



The importance of environment: deposition of pollution

Colonna Antonina





Colonna Traiana

Different micro-clima

- Concentration
- Humidity
- Wind
- Surface rugosity
- Chemical reaction
- …

- SO_2, SO_3
- NO, NO_2
- CO_2
- …

Deterioration of marble: the SO2 effect

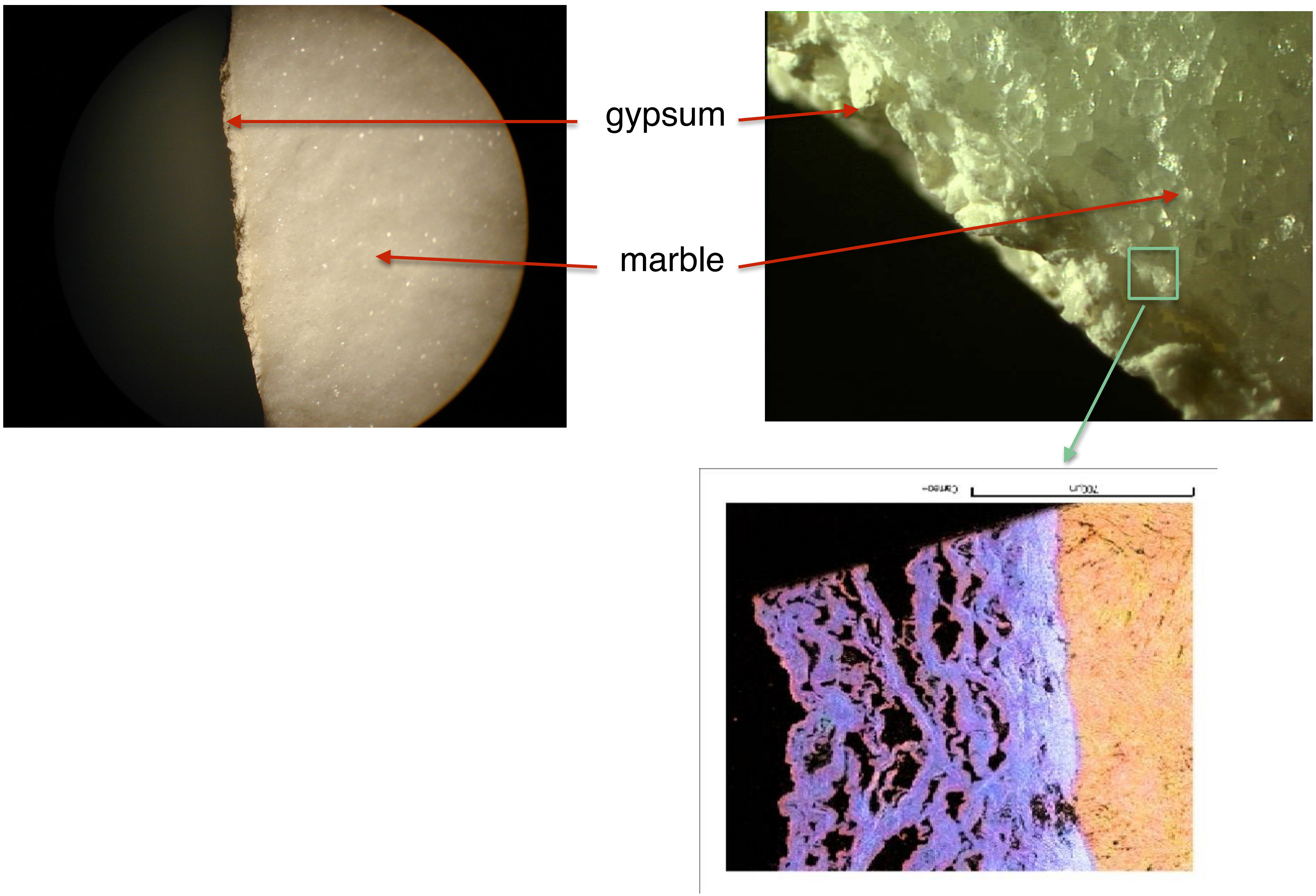
Sulphure dioxide (S02) and nitrogen oxides (in the atmosphere) react with calcium carbonate stones (CaCO3)

Formation of
sulphates and nitrates
(solvability in water)

They may be drained away

They may form a crust (possibly exfoliating)

The mechanism: SO2 + CaCO3



Sulphation crusts

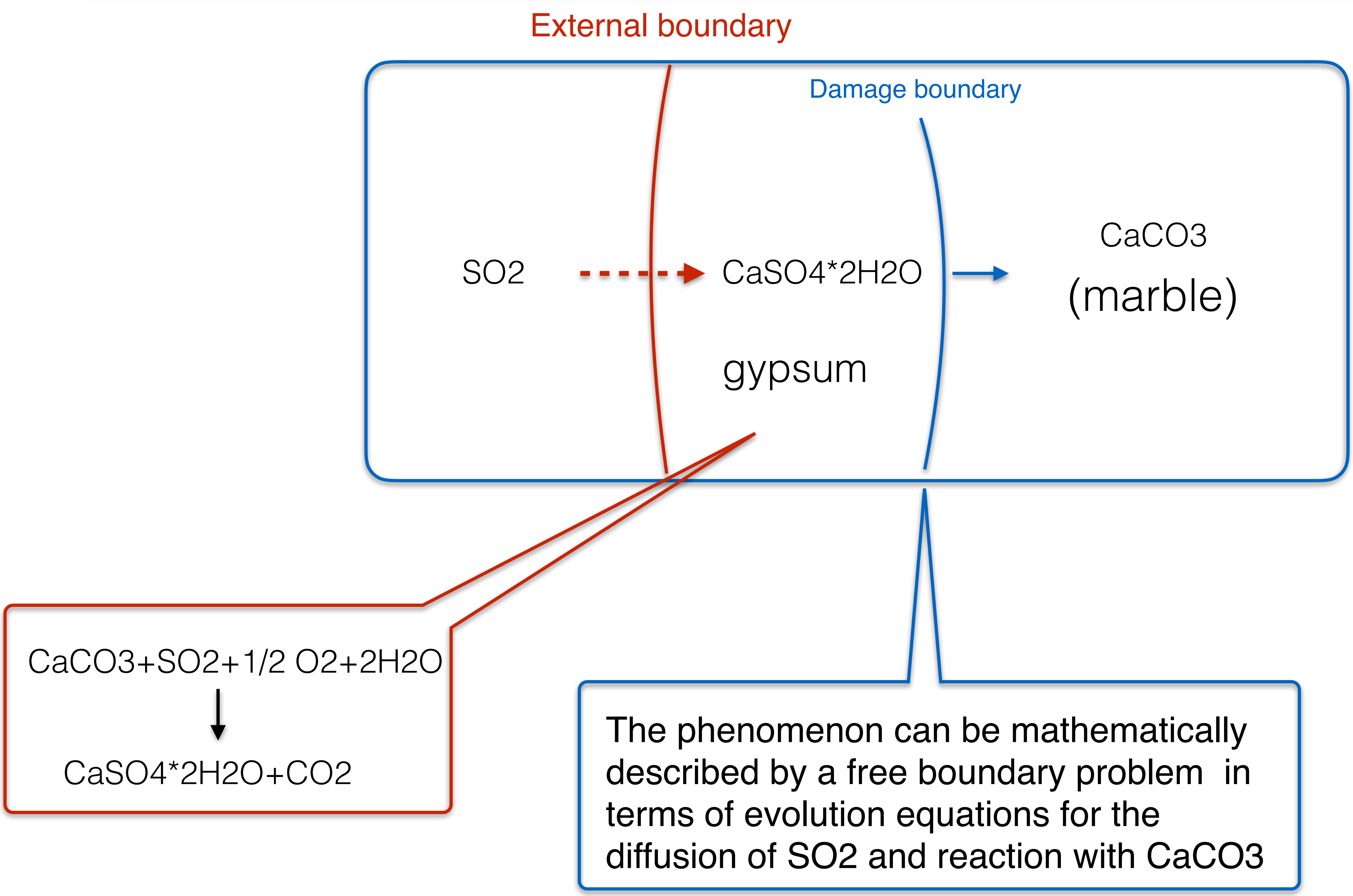
Crust increases the rate of the stone degradation

Volume increases: gypsum has a volume greater than calcium carbonate (generating stress concentration: damage)

Different thermal expansion

Permeability and diffusivity reduction: water retention

The model


External boundary
Damage boundary
SO2
CaSO4*2H2O
gypsum
CaCO3
(marble)
CaCO3+SO2+1/2 O2+2H2O
CaSO4*2H2O+CO2
The phenomenon can be mathematically described by a free boundary problem in terms of evolution equations for the diffusion of SO2 and reaction with CaCO3

A simple model (Natalini, Freddi et al.): c CaCO3 density, s SO2 porous density

Hydrodynamical models: accurate numerical approximation by finite elements or finite differences methods

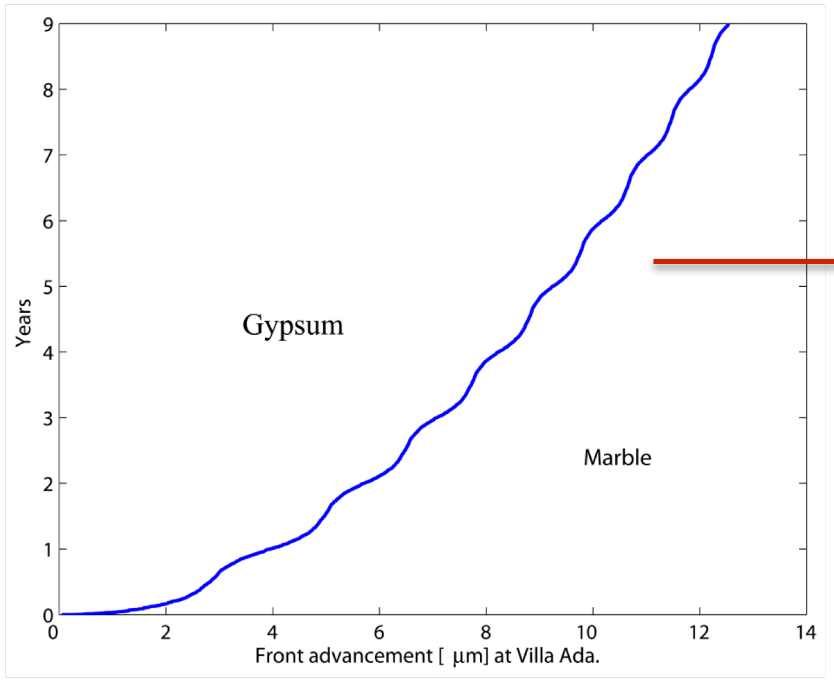
Fick law

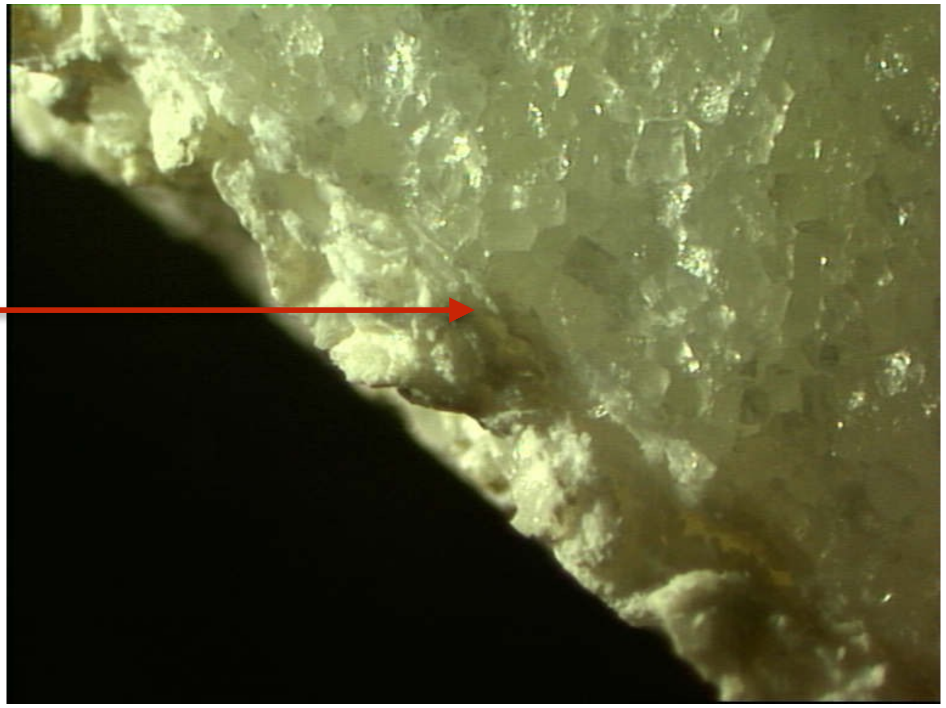
porosity

$$\partial_t(\phi(c)s) - \mathrm{div}\,(\phi(c)\nabla s) = -\phi(c)cs$$
$$\partial_t c = -\phi(c)cs$$

Understanding of physical process, adaptation of the model to more complex situations (including damage factors), affective calibration against experimental data

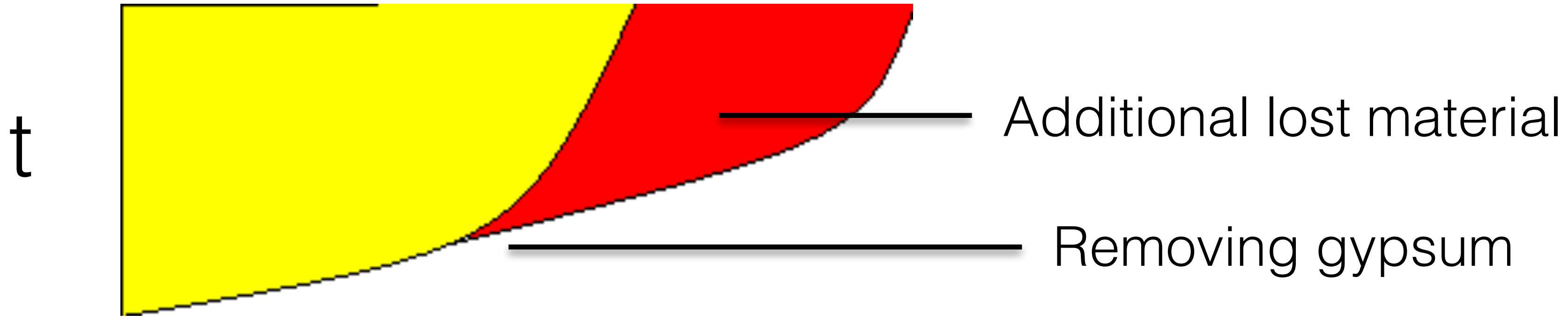
The increasing of the crust



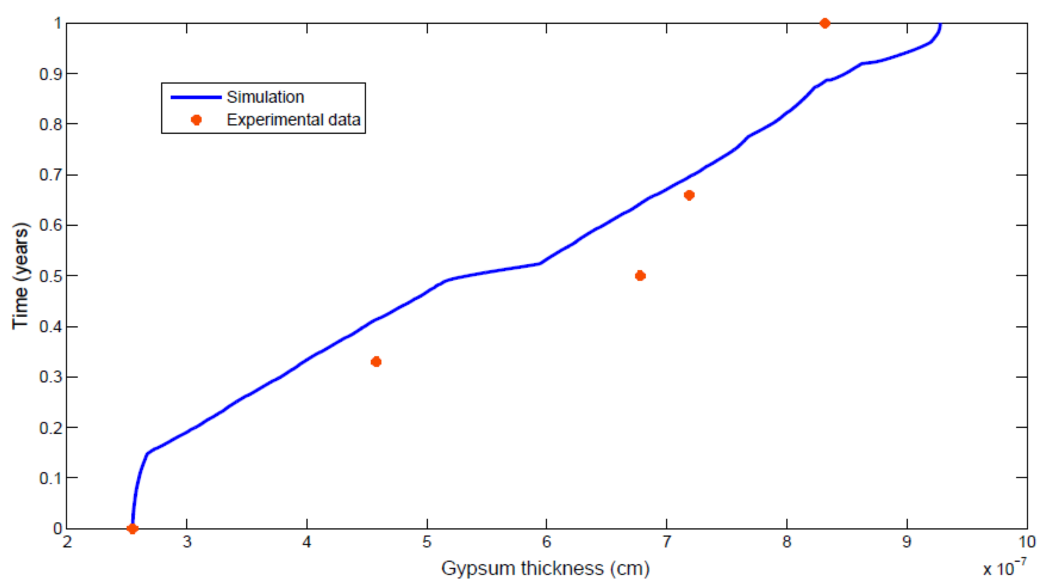


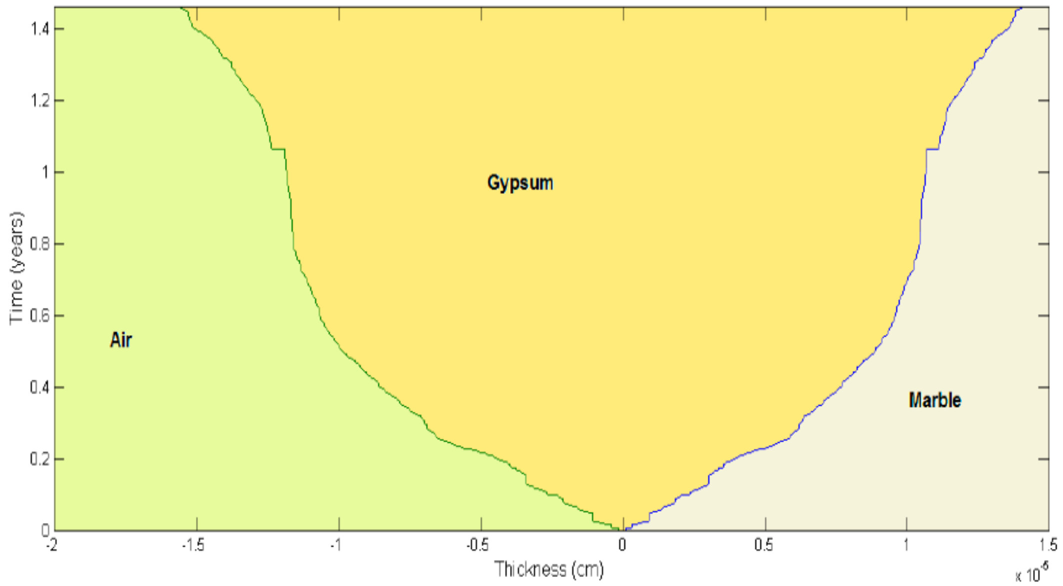
Crust increases with an order of $\sqrt{t}$

Consequence: removing gypsum increases the amount of lost marble



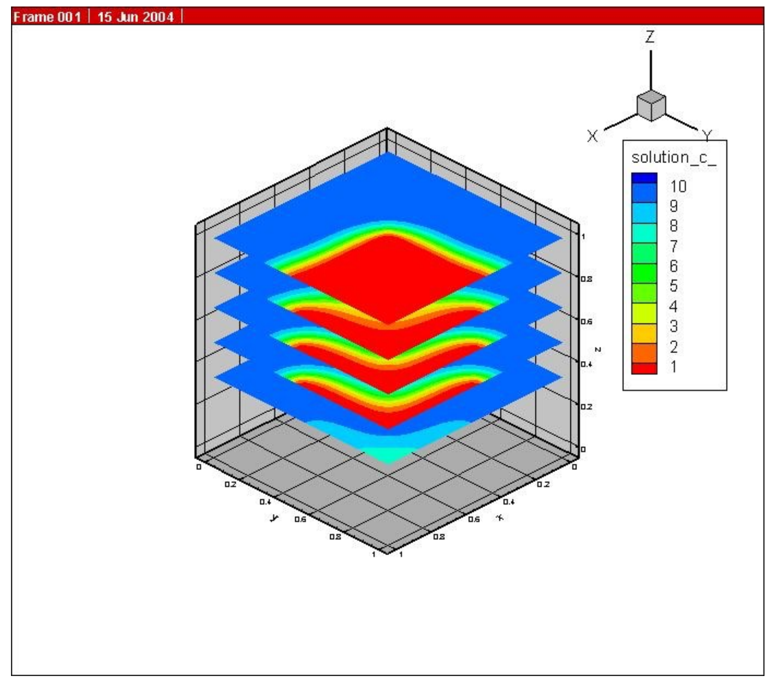
A Project: Il Vittoriano (Rome) 2009-2011

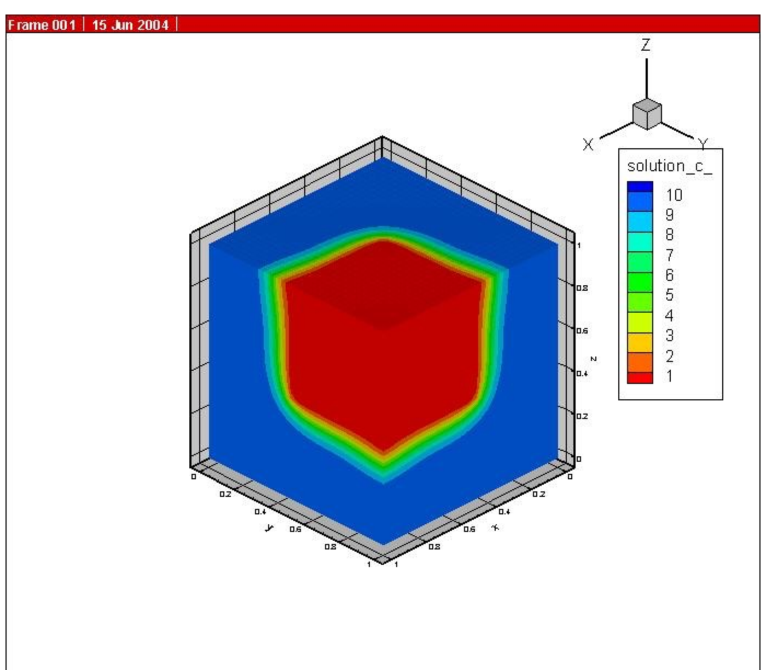


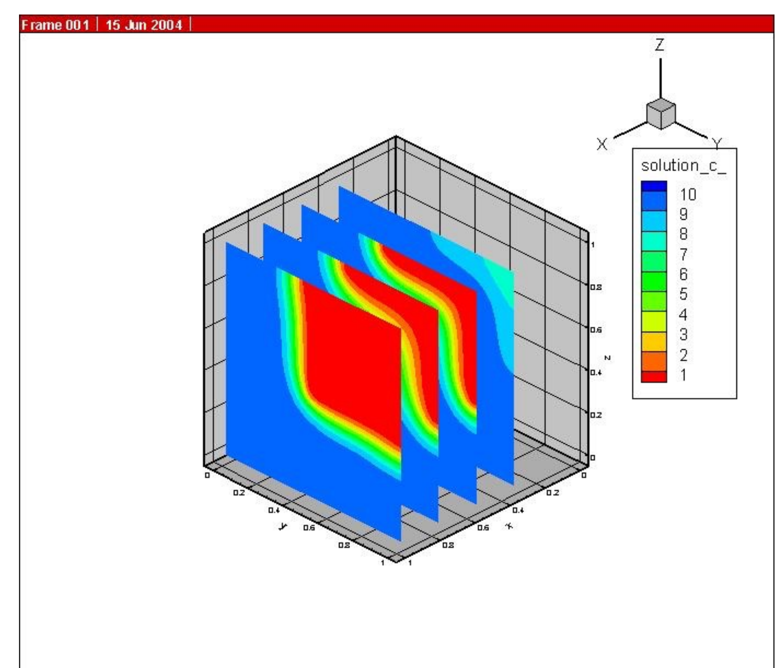


Funded by Ministero dei Beni Culturali
Main Sponsor: Direzione generale dei Beni culturali del Lazio
Project Leader: E. Giani (ISRC-MIBAC)
Participants:
ISCR - MIBAC: C. Cacace, A. Giovagnoli, L. Gordini
CISTeC - "Sapienza" Univ. Roma : M.L. Santarelli, P. Bracciale
IAC - CNR: R. Natalini, F. Clarelli, B. De Filippo.

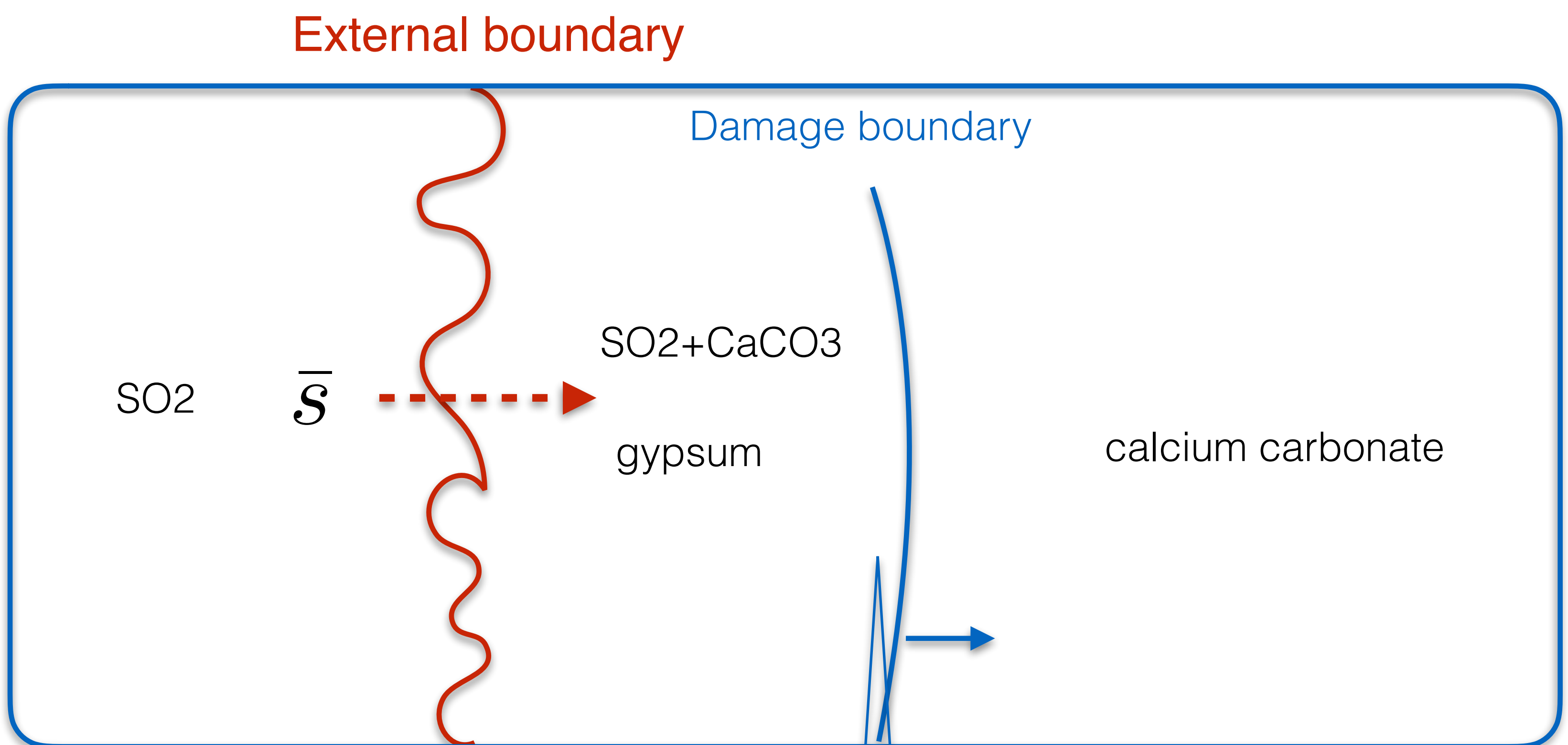
Inside the material (Natalini & Freddi)







Surface damage (rugosity) influencing the phenomenon

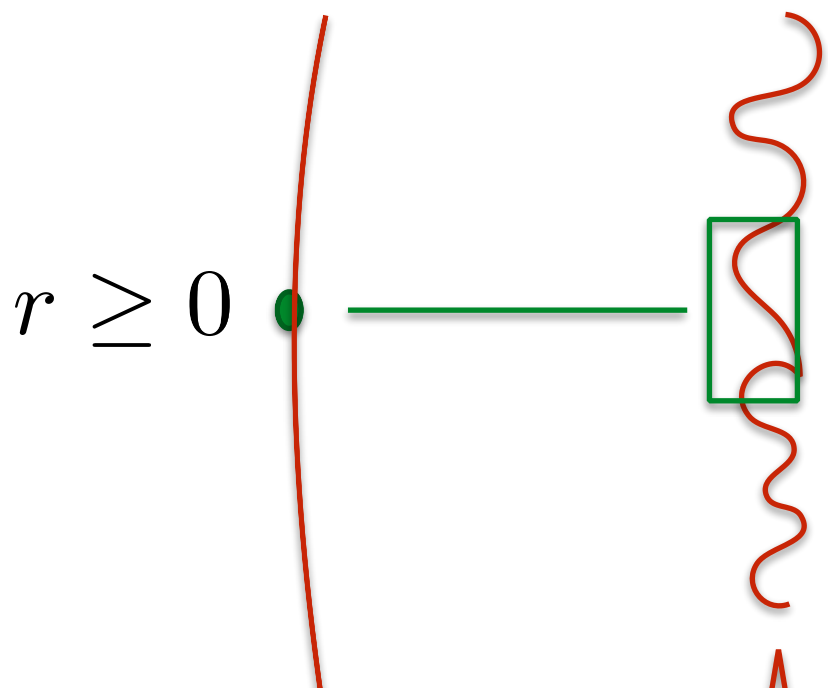


$$\phi(c)\nabla s \cdot \mathbf{n} = -\nu(r)(s - \bar{s})$$

the coefficient depends on the rugosity

$$\partial_t(\phi(c)s) - \mathrm{div}\ (\phi(c)\nabla s) = -\phi(c)cs$$
$$\partial_t c = -\phi(c)cs$$

The equation for the rugosity evolution



The evolution of the rugosity depends on:

- wearing agents (wind, rain, ...)
- the porosity
- the presence of SO2
- the cohesion of the material,
- ...

$$\partial_t r + \partial W(r) + \Psi'(r) + G(r, c, s) \overset{\ni}{=} F$$

Surface “damage” equation
by use of a phase transition approach

The evolution PDE system

In the volume

$$\partial_t(\phi(c)s) - \mathrm{div}\,(\phi(c)\nabla s) = -\lambda\phi(c)sc \quad \text{in } \Omega\times(0,T)$$

$$\partial_t c = -\lambda\phi(c)sc \quad \text{in } \Omega\times(0,T)$$

Transmission law

$$\phi(c)\partial_n s = -\nu(r)(s_{|\Gamma} - \bar{s}) \quad \text{on } \Gamma\times(0,T)$$

On the surface

$$\partial_t r + \partial W(r) + \Psi'(r) + G(r,c,s) \ni F \quad \text{on } \Gamma\times(0,T)$$

Initial conditions

$$s(0) = s_0, \quad c(0) = c_0, \quad r(0) = r_0$$

A possible constraint to ensure r uniformly bounded and non-negative

$$\partial W(r) = \partial I_{[0,r_l]}(r) = \begin{cases} 0 \text{ if } r\in(0,r_l) \\ [0,+\infty) \text{ if } r = r_l \\ (-\infty,0] \text{ if } r = 0 \end{cases}$$

The choice of the potentials

$\partial W(r) (\text{e.g. } \partial I_{[0,r_l]})$ maximal montone operator (internal constraint)

G depends on s and c through the porosity function

$\phi(c)$ the porosity function, it is assumed $\phi(c) = A + Bc$

$\lambda > 0$ reaction coefficient

$\nu(\cdot) \geq 0$ the permeability coefficient (increasing with r)

$\Psi'(r)$ possibly non-monotone dynamics on r

The assumptions

$W : [0, +\infty) \to [0, +\infty]$ is convex, and l.s.c., $W(0) = 0$

$\Psi \in W^{2,\infty}(\mathbb{R}), \quad G \in W^{1,\infty}(\mathbb{R}^3), \quad F \in L^2(0, T; L^2(\Gamma))$

$\bar{s} \in H^{1/2}(\Gamma), \quad \bar{s} \geq 0$ a.e. in Γ

$\nu \in W^{1,\infty}(\mathbb{R}), \quad \nu \geq 0$ a.e. in $\mathbb{R}$

$c_0 \in H^2(\Omega), \quad 0 \leq c_0(x) \leq C_0 \ \forall x \in \Omega,$

$s_0 \in H^2(\Omega), \quad s_0(x) \geq 0 \ \forall x \in \Omega,$

$r_0 \in L^2(\Gamma), \quad W(r_0) \in L^1(\Gamma), \quad r_0 \geq 0$ a.e. in Γ

$A > 0, \ A + BC_0 > 0$

$B \leq \dfrac{1}{S_0}$ and $\bar{s}(x) \leq S_0$ for a.a. $x \in \Gamma$, with $S_0 > 0$ s.t. $s_0(x) \leq S_0 \ \forall x \in \Omega.$

Statement of the problem

$$
\begin{aligned}
& s \in H^1(0,T;L^2(\Omega)) \cap L^\infty(0,T;H^1(\Omega)) \cap L^2(0,T;H^2(\Omega)), \\
& c \in H^1(0,T;H^2(\Omega)), \\
& r \in H^1(0,T;L^2(\Gamma)), \\
& s \geq 0, \quad 0 \leq c \leq C_0, \quad \text{a.e. in } \Omega \times (0,T),
\end{aligned}
$$

$$
\begin{aligned}
& \partial_t(\phi(c)s) - \operatorname{div}\,(\phi(c)\nabla s) = -\phi(c)sc, \ \text{a.e. in } \Omega \times (0,T), \\
& \phi(c)\partial_n s = -\nu(r)(s - \bar{s}), \ \text{a.e. on } \Gamma \times (0,T), \\
& \partial_t c = -\phi(c)cs, \ \text{a.e. in } \Omega \times (0,T), \\
& \partial_t r + \xi + \Psi'(r) + G(r,c,s) = F, \quad \xi \in \partial W(r), \quad \text{a.e. on } \Gamma \times (0,T), \\
& s(0) = s_0, \ c(0) = c_0, \ \text{a.e. in } \Omega, \qquad r(0) = r_0, \ \text{a.e. on } \Gamma.
\end{aligned}
$$

The (global in time) existence result [B., Cavaterra, Freddi, Grasselli, Natalini, '17]

Under suitable assumptions there exists a unique solution in (0,T) fulfilling

$$
\begin{aligned}
& s \in H^1(0,T;L^2(\Omega)) \cap L^\infty(0,T;H^1(\Omega)) \cap L^2(0,T;H^2(\Omega)), \\
& c \in H^1(0,T;H^2(\Omega)), \\
& r \in H^1(0,T;L^2(\Gamma)) \\
& s \in W^{1,\infty}(0,T;L^2(\Omega)) \cap H^1(0,T;H^1(\Omega)) \cap L^\infty(0,T;H^2(\Omega)), \\
& c \in W^{1,\infty}(0,T;H^2(\Omega)), \\
& 0 \leq s \leq S_0, \quad 0 \leq c \leq C_0 \quad \text{a.e. in } \Omega \times (0,T), \\
& \xi \in L^2(0,T;L^2(\Gamma)).
\end{aligned}
$$

Outline of the proof

1. Local in time result by a fixed point theorem (contraction argument): a Banach theorem for a suitable norm to ensure (at least for small time interval) that we can define an operator on

$$\mathcal{X}_{R,T} := \{s \in L^2(0,T;H^2(\Omega)) : s \geq 0, \|s\|_{L^\infty([0,T]:L^2(\Omega))\cap L^2(0,T;H^2(\Omega)) \leq R}\}$$

and we prove that the operator is a contracting map w.r.t. the norm of

$$L^\infty(0,T;L^2(\Omega)) \cap L^2(0,T;H^2(\Omega))$$

2. Global estimates on the whole time interval (under further assumptions on the data): to get global estimates, independent of time, we need further regularity of the solutions

3. Extending the local solution to the whole time interval

The fixed point argument

1- $$\widehat{s} \in \mathcal{X}_{R,T} \to \widehat{c} : \|\widehat{c}\|_{H^1(0,T;H^2(\Omega))} \leq C(R)$$

$$\partial_t c = -Ac\widehat{s} - Bc^2\widehat{s}, \text{ a.e. in } \Omega.$$

$$\widehat{c}(x,t) = \frac{Ac_0(x)}{(A + Bc_0(x))e^{A\int_0^t \widehat{s}(x,\tau)d\tau} - Bc_0(x)}, \qquad \text{in } \Omega \times (0,T).$$

2- $$(\widehat{s}, \widehat{c}) \to \widehat{r} : \|\widehat{r}\|_{H^1(0,T;L^2(\Gamma)} \leq C(R)$$

$$\partial_t r + \xi + \Psi'(r) + G(r, \widehat{c}, \widehat{s}) = F,\ \xi \in \partial W(r) \text{a.e. in } (0,T)$$

The fixed point argument

3- $(\widehat{c}, \widehat{r}) \to s$

$$\|s\|_{W^{1,\infty}(0,T;L^2(\Omega))\cap H^1(0,T;H^1(\Omega))\cap L^\infty(0,T;H^2(\Omega))} \leq C(R),$$

$$s \geq 0$$

4-

$$\|s\|_{L^\infty(0,T;L^2(\Omega))\cap L^2(0,T;H^2(\Omega))}$$
$$\leq T\|s_t\|_{L^\infty(0,T;L^2(\Omega))} + \|s_0\|_{L^2(\Omega)} + T^{1/2}\|s\|_{L^\infty(0,T;H^2(\Omega))}$$
$$\leq (T + T^{1/2})C(R) + \|s_0\|_{L^2(\Omega)} \quad \leq R \quad \text{for small } T$$

The fixed point argument - the contraction

$$\|(s_1 - s_2)(t)\|^2_{L^2(\Omega)} + \int_0^t \|s_1 - s_2\|^2_{H^1(\Omega)}$$
$$\leq C(R)\left(\int_0^t \|\widehat{s}_1 - \widehat{s}_2\|^2_{L^2(\Omega)} + \int_0^t \|\widehat{s}_1 - \widehat{s}_2\|^2_{L^2(0,s;H^1(\Omega))}\right).$$

For large j the operator $\mathcal{S}^j$, with $s = \mathcal{S}(\widehat{s})$ is a contraction

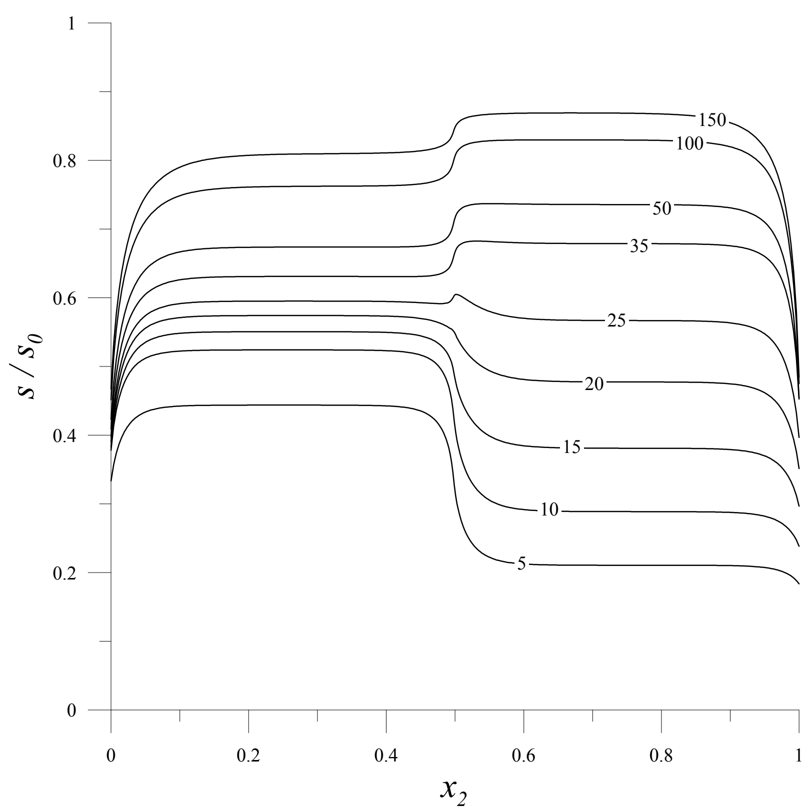
To extend the solution

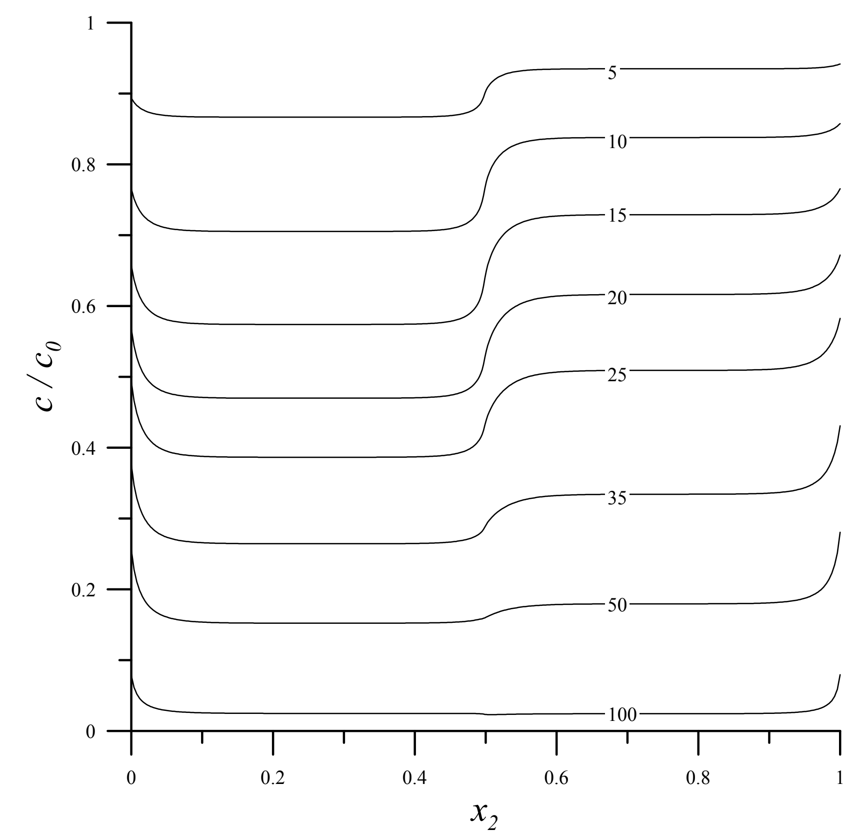
$$0 \leq s \leq S_0$$

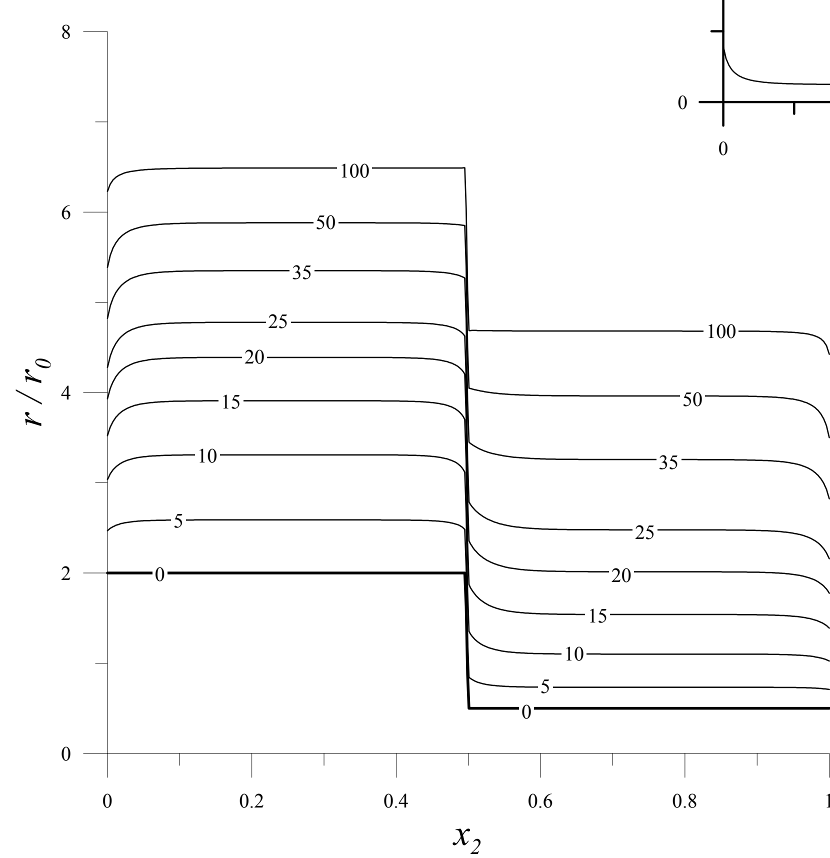
$$\|s\|_{W^{1,\infty}(0,T;L^2(\Omega))\cap H^1(0,T;H^1(\Omega))\cap L^\infty(0,T;H^2(\Omega))} \leq C$$

Choosing $R > 0$ with $R \geq T^{1/2}C$, $\mathcal{S}$ is a contraction in $\mathcal{X}_{R,T}$

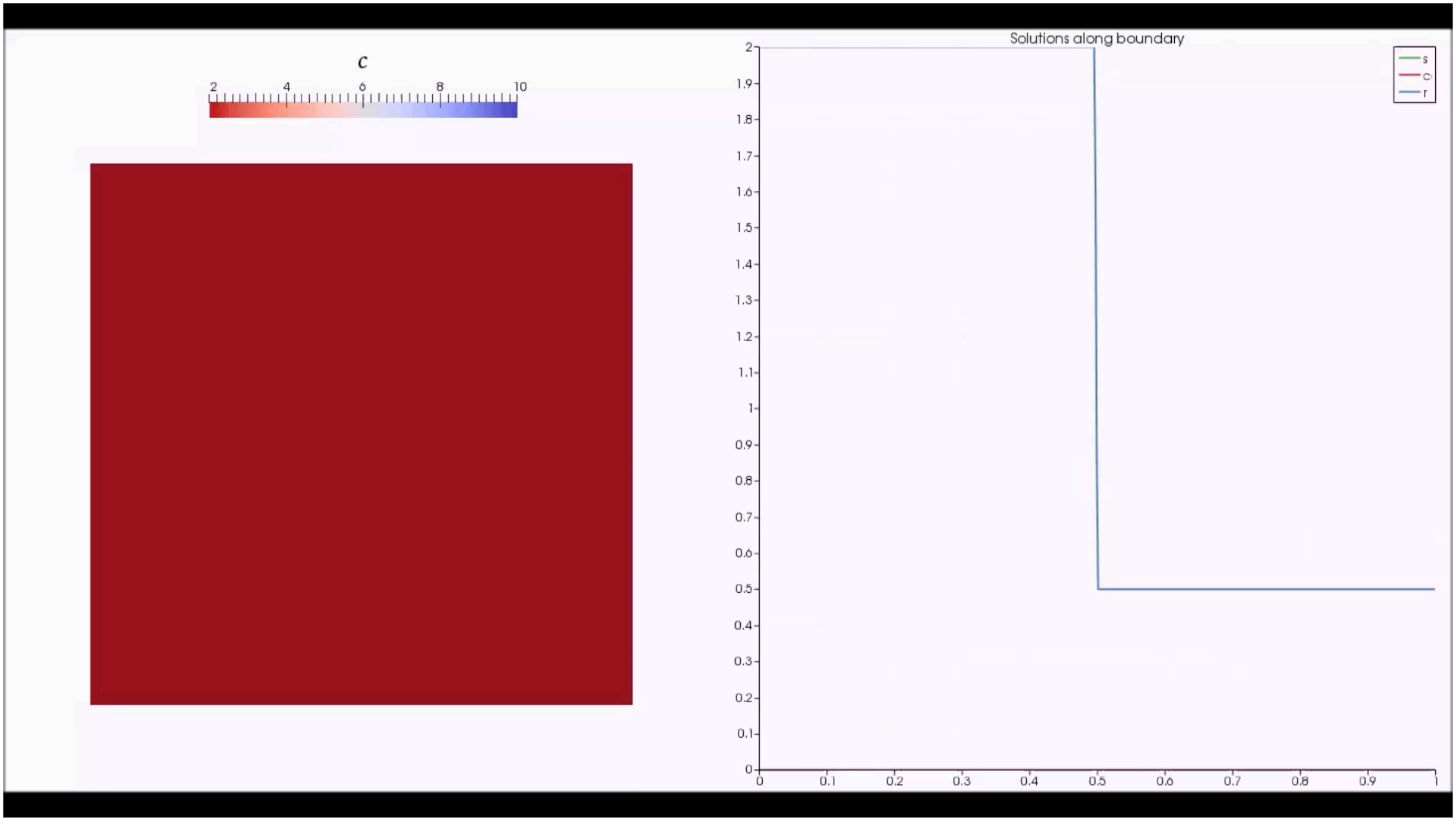
Some computations
piecewise linear law for permeability coefficient in r



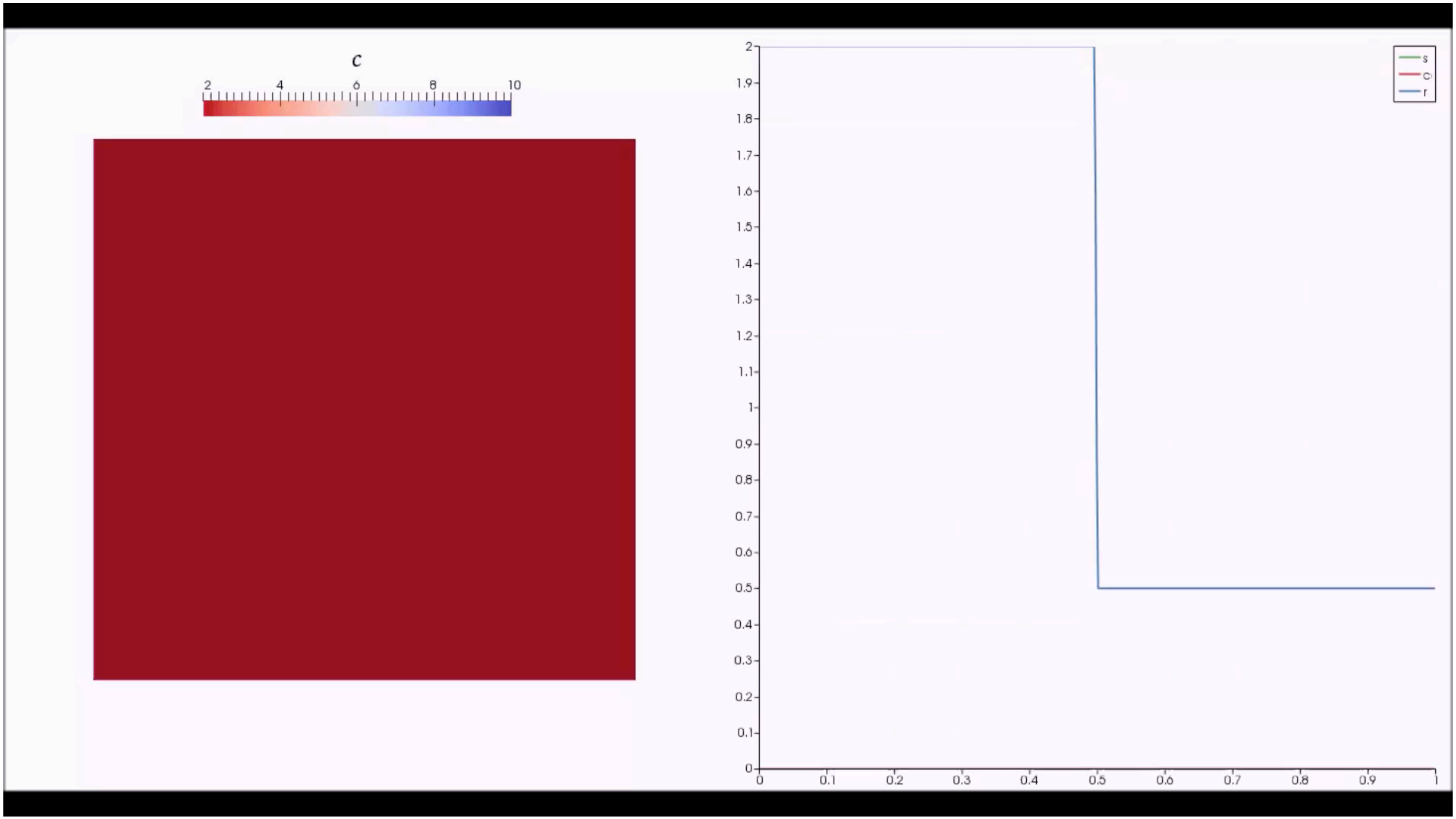




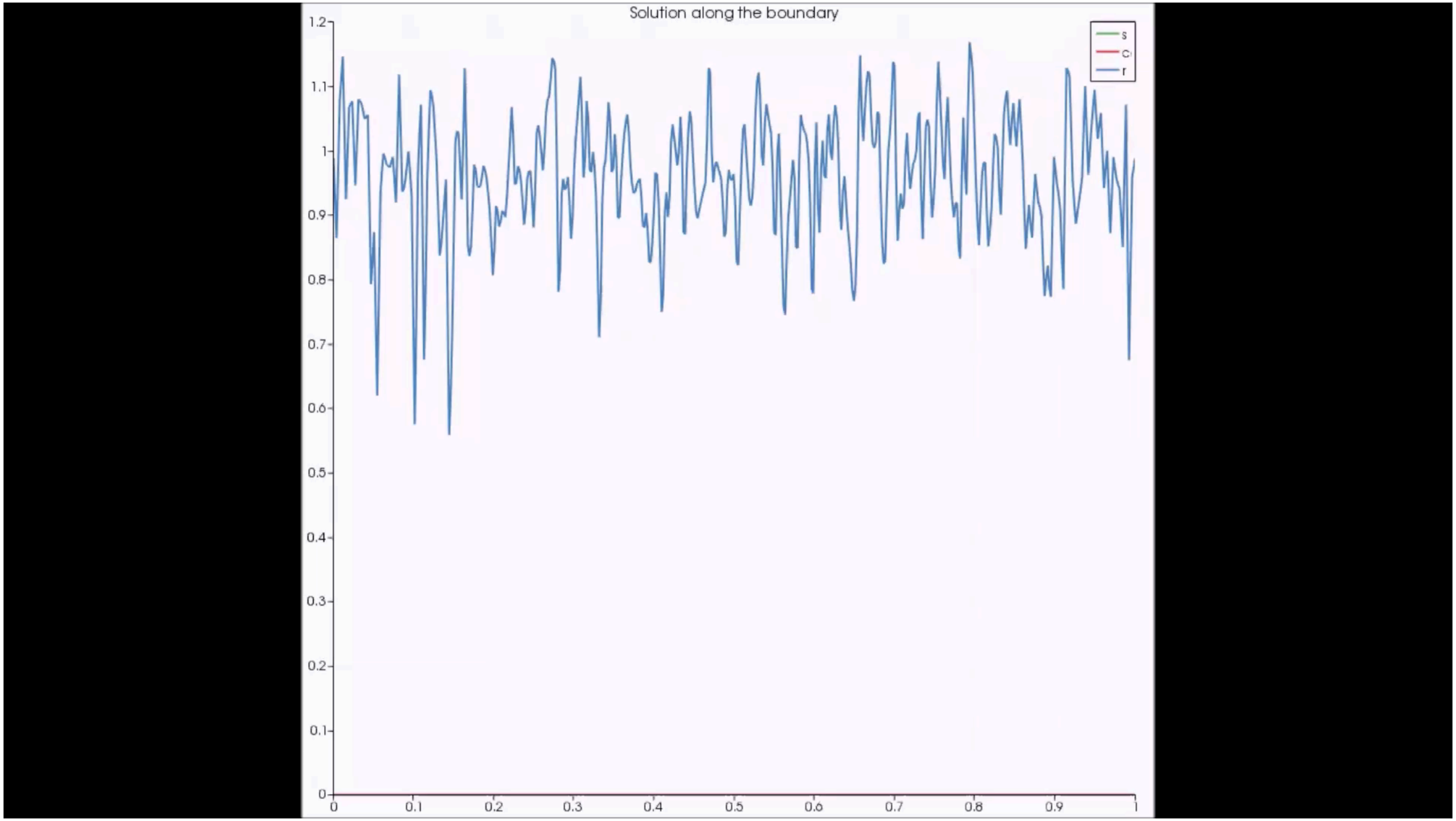
Some computations
piecewise linear law for permeability coefficient in r



Some computations
parabolic law for permeability coefficient in r



Some computations - r random evolution



Next steps

- Properties of the solutions and dependence on physical parameters
- Calibration and validation of the model with experimental data
- Including more complex phenomena: combining mechanical effects and volume damage
- ….

B., Cavaterra, Freddi, Grasselli, Natalini,
A nonlinear model for marble sulphating including surface rugosity: theoretical and numerical results, 2017

Biological and bio-inspired locomotion at small scales

Antonio DeSimone

SISSA-International School for Advanced Studies

http://people.sissa.it/~desimone/

Based on joint work with:

F. Alouges (Ecole Polytechnique), M. Arroyo (UPC, Barcelona), A. Beran (OGS, Trieste)

and, from SISSA:

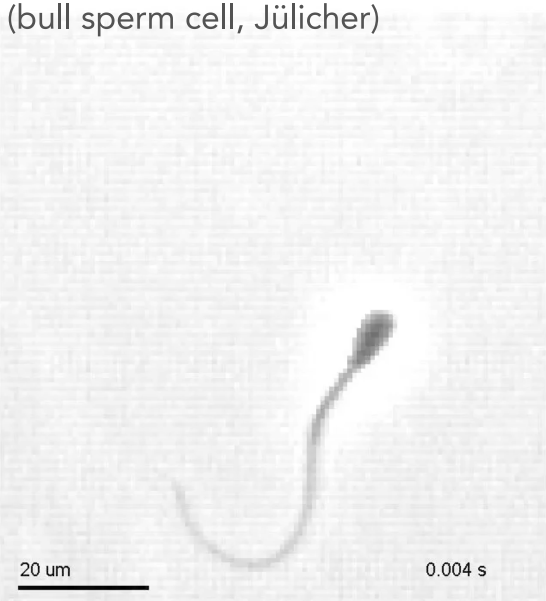
G. Cicconofri, **N. Giuliani**, L. Heltai, A. Lucantonio, **A. Montino**, G. Noselli, M. Rossi

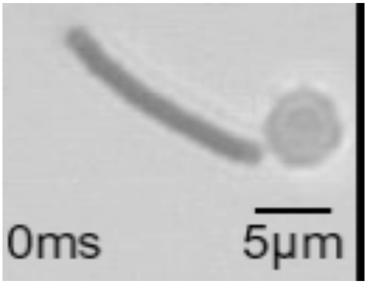
[G. Dal Maso, **P. Gidoni**, **M. Morandotti**]

Giornata Federazione Italiana Matematica Applicata, CNR-Roma, 27.10.17

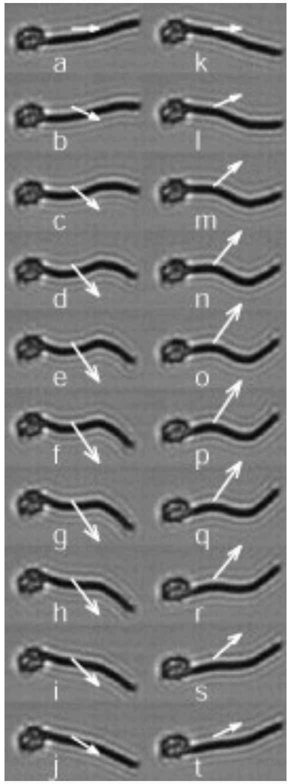
BIOLOGICAL MACHINES
Bio-inspired (swimming) micro-motility

(bull sperm cell, Jülicher)





R. Dreyfus et al.: Nature (2005)



A sperm-bot ???

Technology: how do we make it autonomous? (power source)
Science: how can we steer it precisely? (direction of motion)

Outline

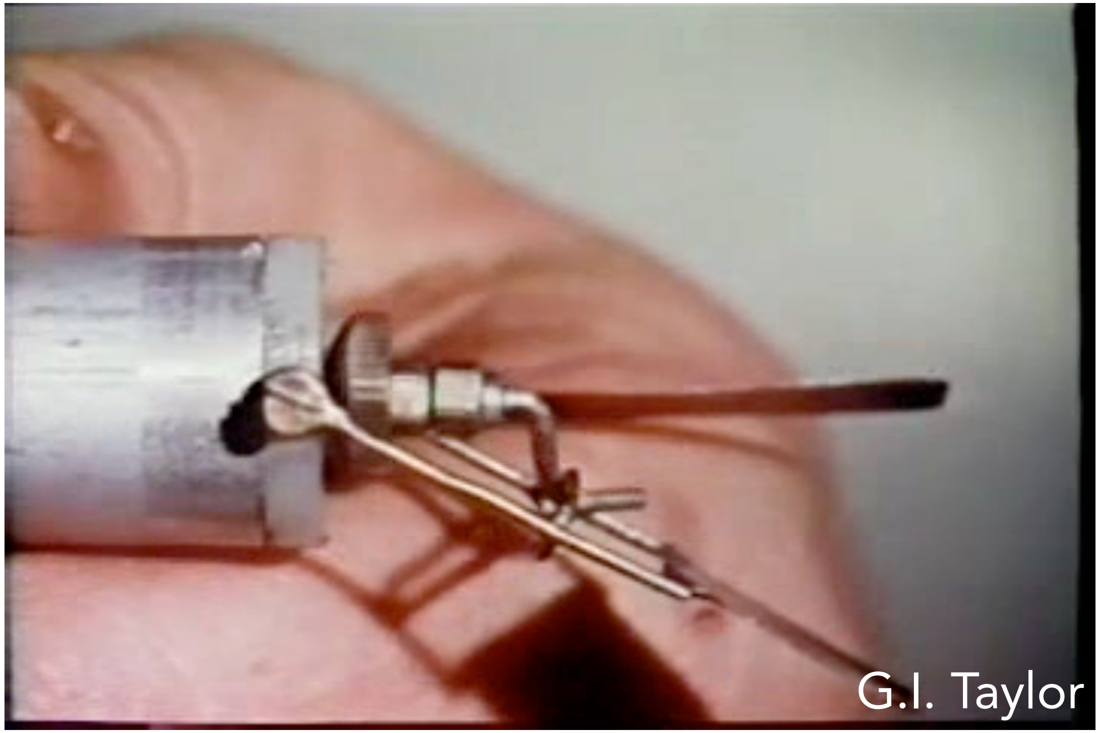
Swimming ~~Locomotion~~ =
shape change +
interaction with surrounding ~~medium~~ fluid

- 1. How to generate controlled motion by prescribing time-periodic evolving shapes? (locomotion principles)
- 2. How do unicellular organisms swim?

Case study: Euglena gracilis

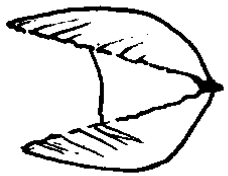
- 3. Metaboly in E. gracilis : how is shape controlled?
- 4. Flagellar propulsion in E. Gracilis
- Outlook

Swimming without inertia is counter-intuitive



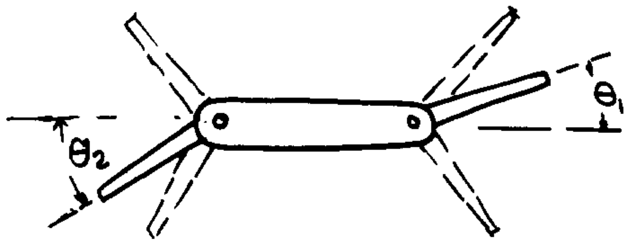
The Scallop Theorem

E. Purcell



(1977: 40 years of Life at low Re)

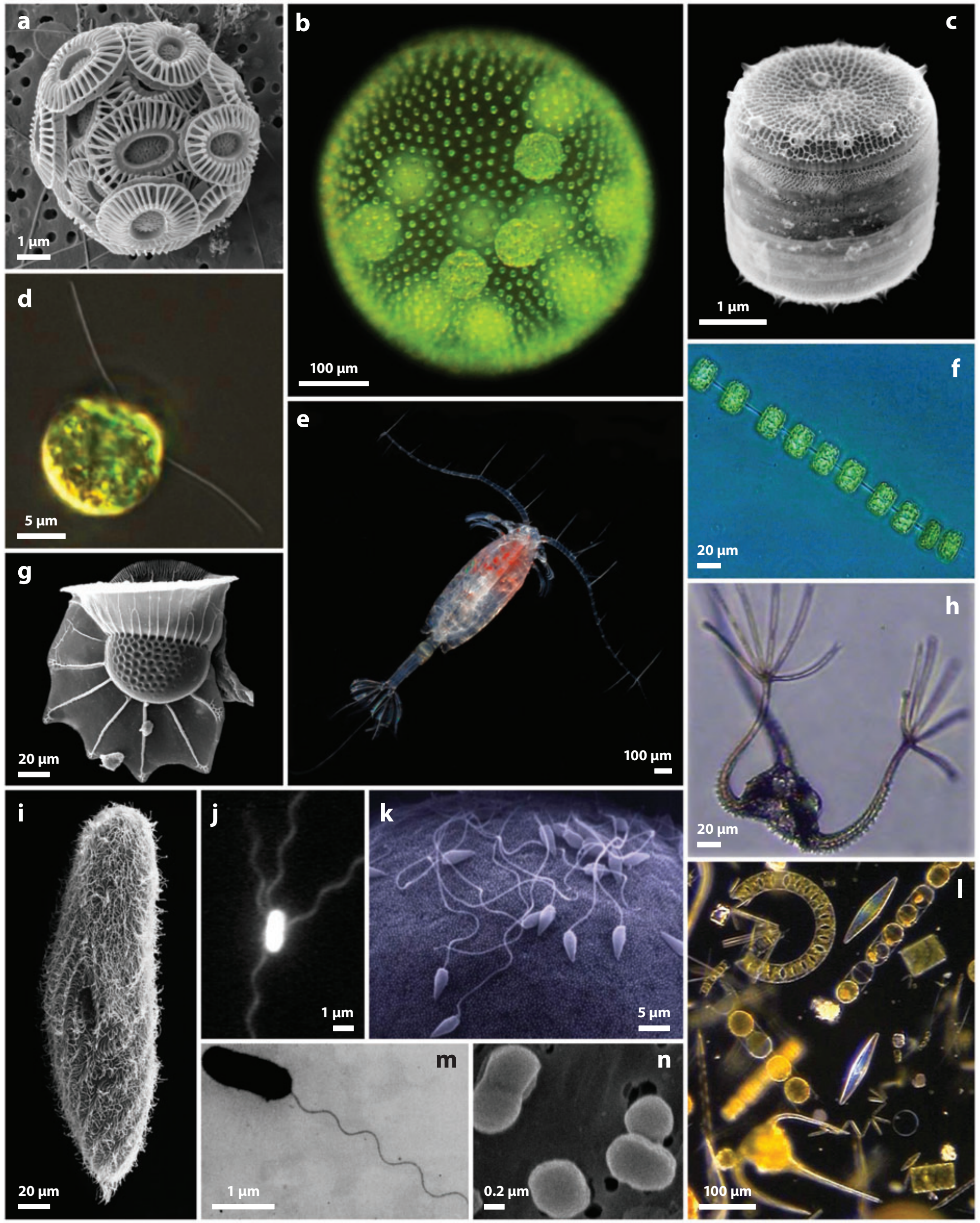
Minimal swimmers

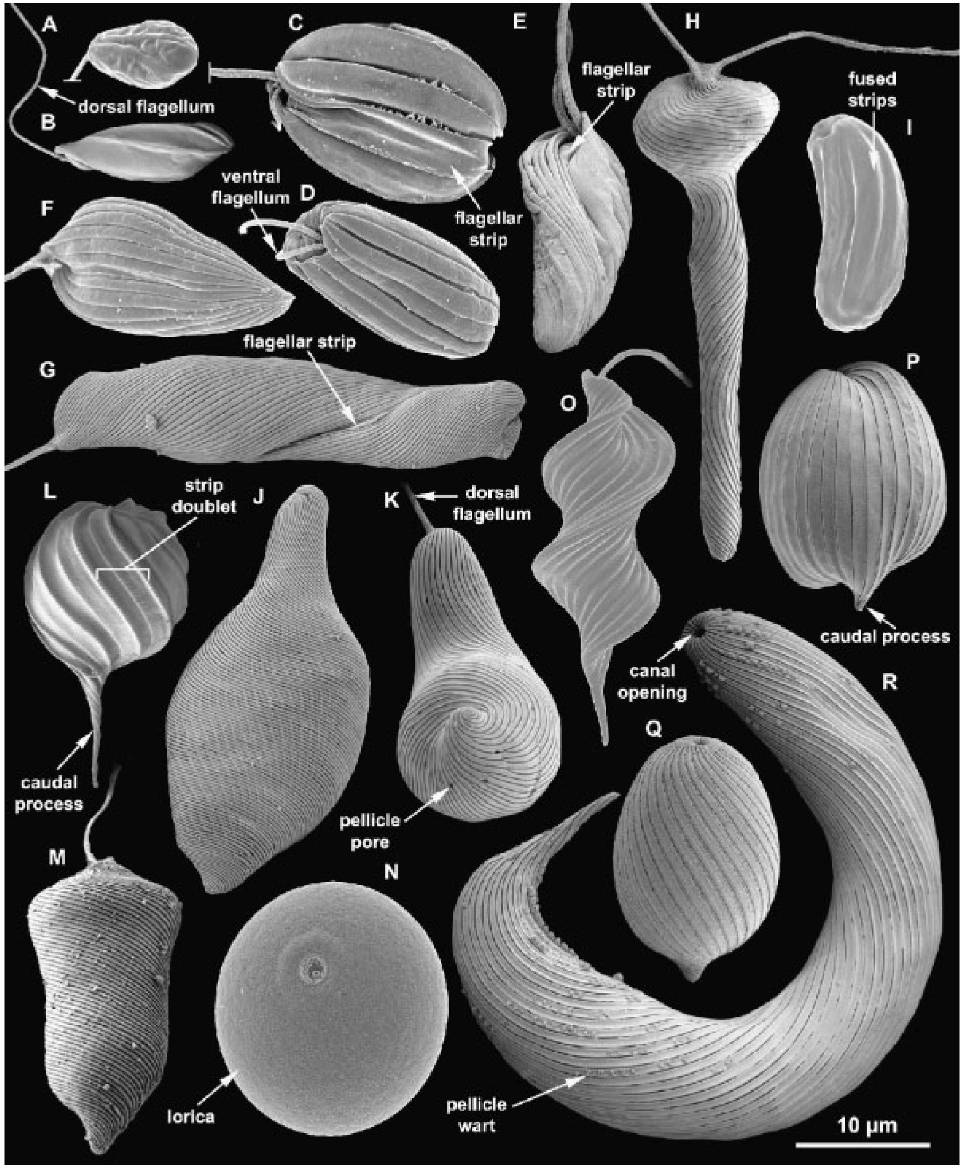


R. Golestanian

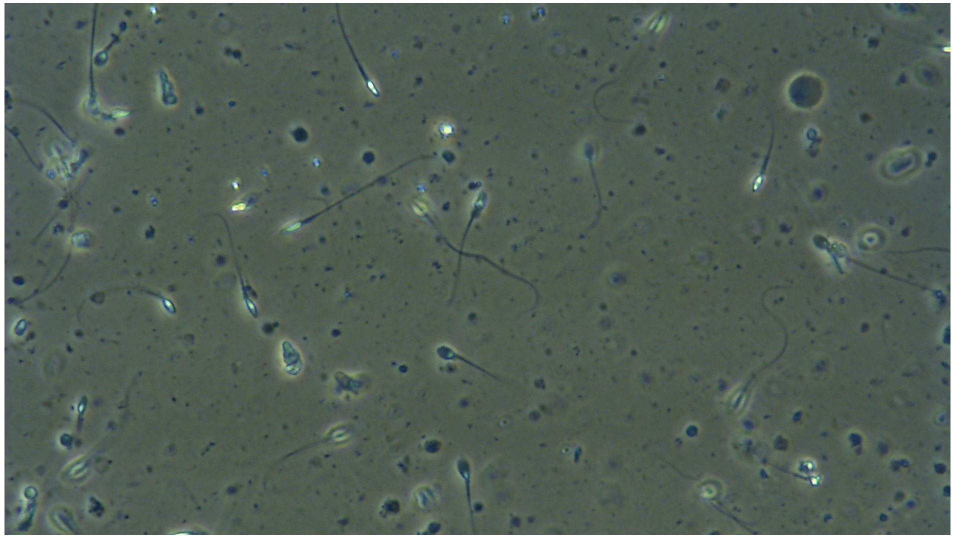
3-sphere DEMO !

2. How do unicellular organisms swim?

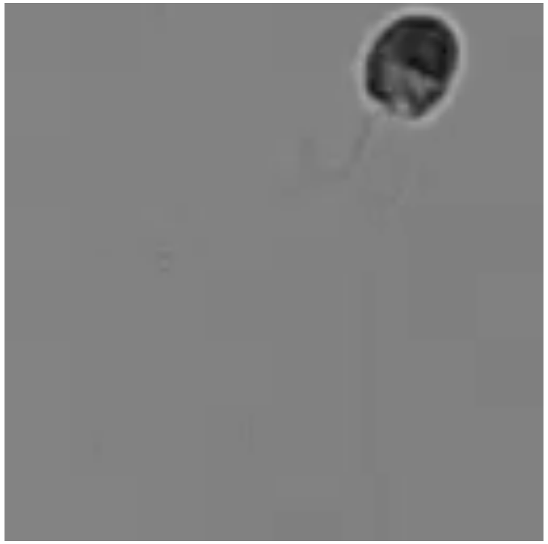




Two well studied principles
(looping in the space of shapes)



(Linear motility of human sperm cells, UWa)

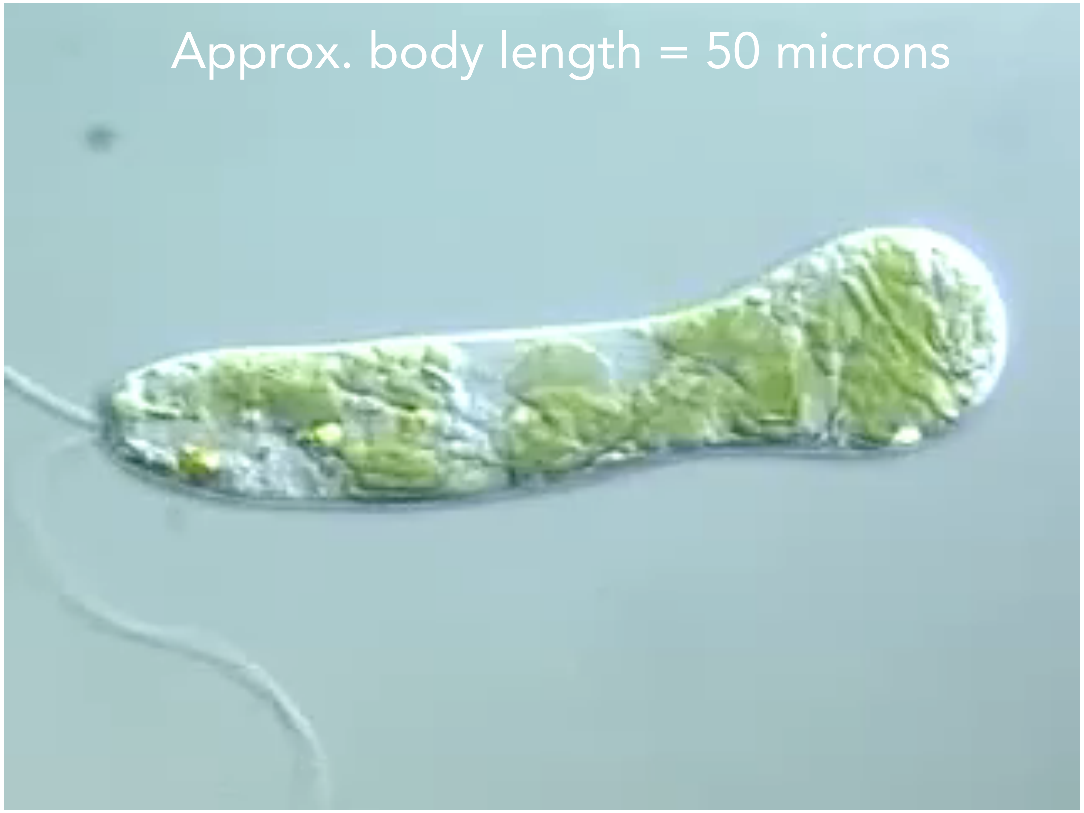


(Chlamydomonas, J. Guasto)

Flagellar beating
(travelling waves of shape)
$\mathrm{Sin}(kx-\omega t)=\mathrm{Cos}(\omega t)\mathrm{Sin}(kx) - \mathrm{Sin}(\omega t)\mathrm{Cos}(kx)$

Breast-stroke
(different shapes in power/recovery
parts of a stroke)

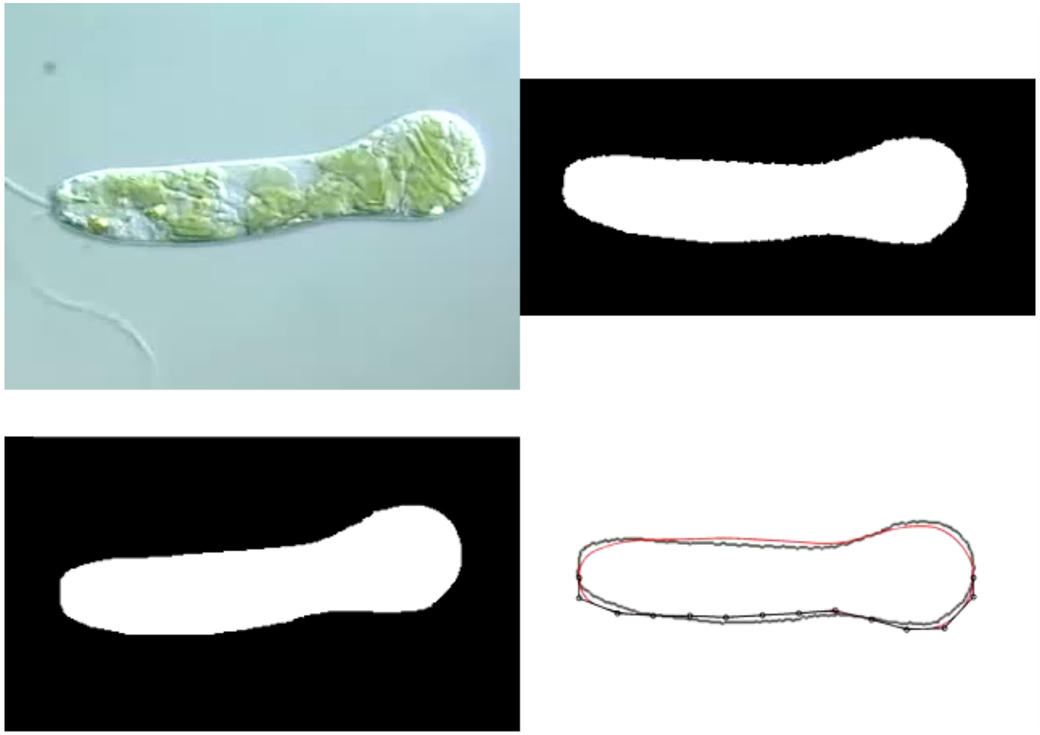
Euglena: unicellular organism with both flagellar motility and “metaboly"

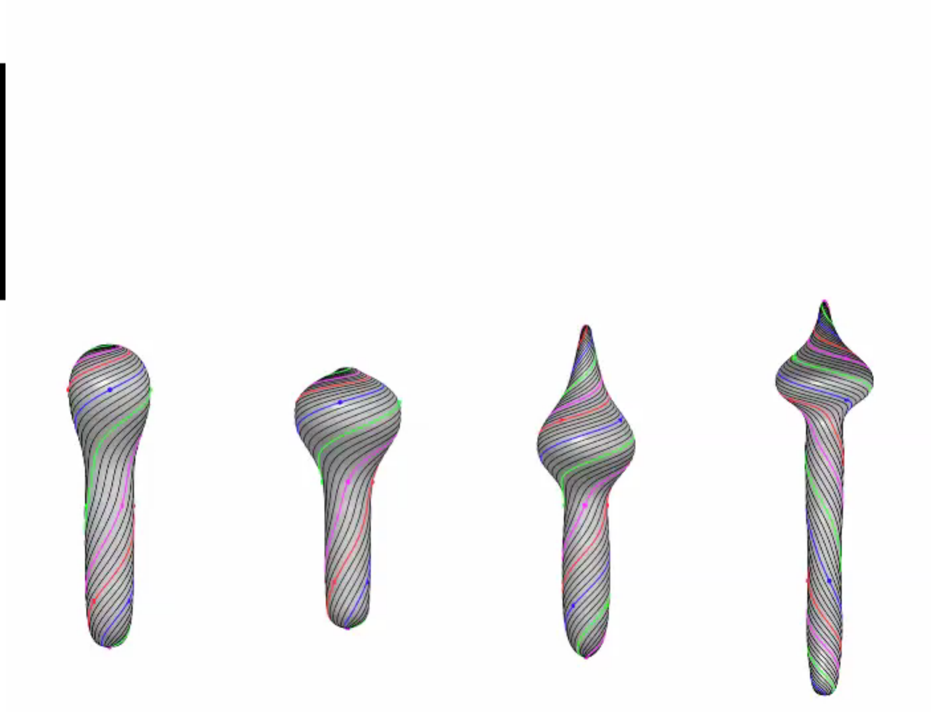


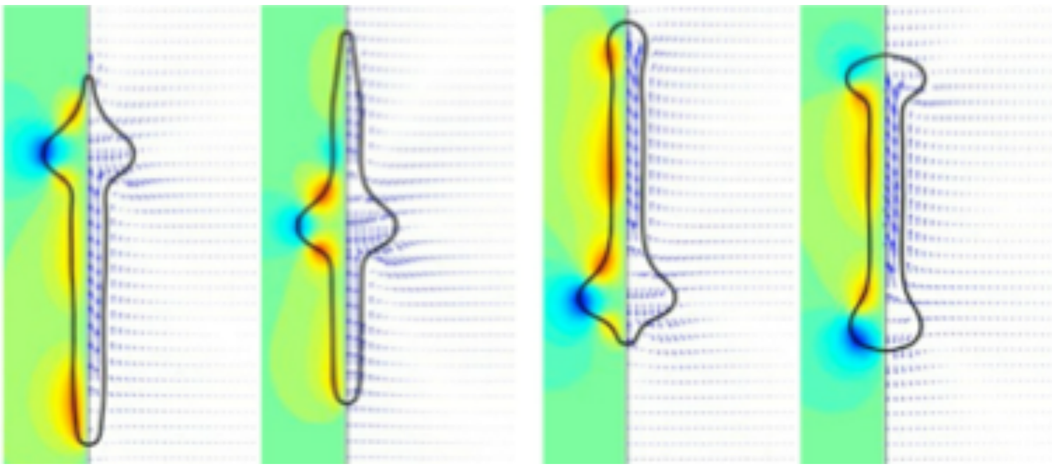
Cell movement	Cell structure needed	Molecular motor	Motor category
Movements through liquid			
Bacterial swimming	Flagella (bacterial)	Flagellar rotor (MotA/MotB)	Rotary
Eukaryotic swimming	Cilia, flagella (eukaryotic)	Dynein	Linear stepper
Metaboly	Unknown	Unknown	Unknown

D. Fletcher, J. Theriot: An introduction to cell motility for the physical scientists. Phys Biol. (2004)

Swimming in Silico: Olympics for Euglenids

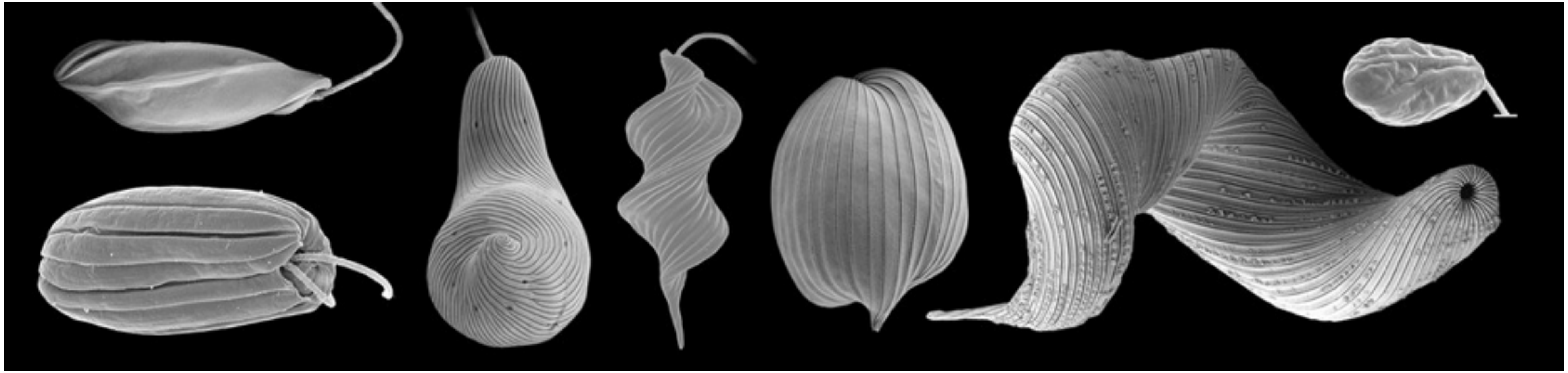




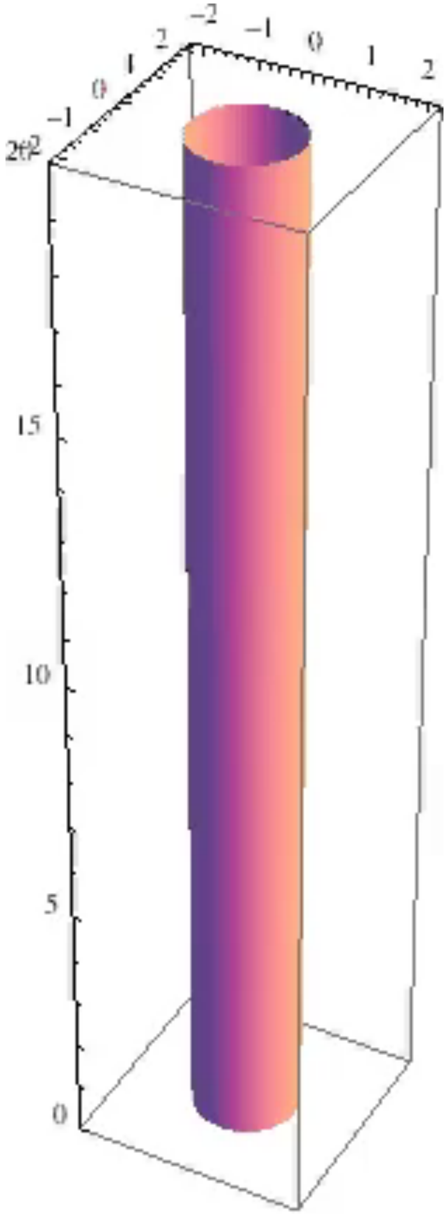


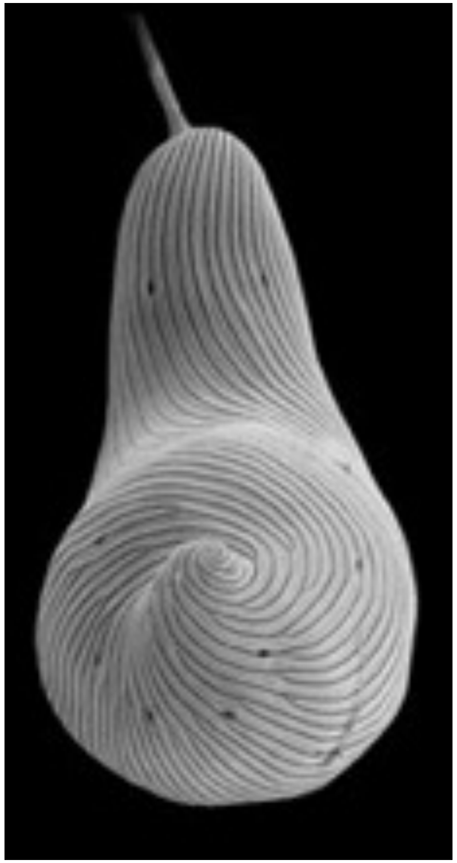
M. Arroyo, D. Milan, L. Heltai, ADS,
PNAS 109, 1784-1789

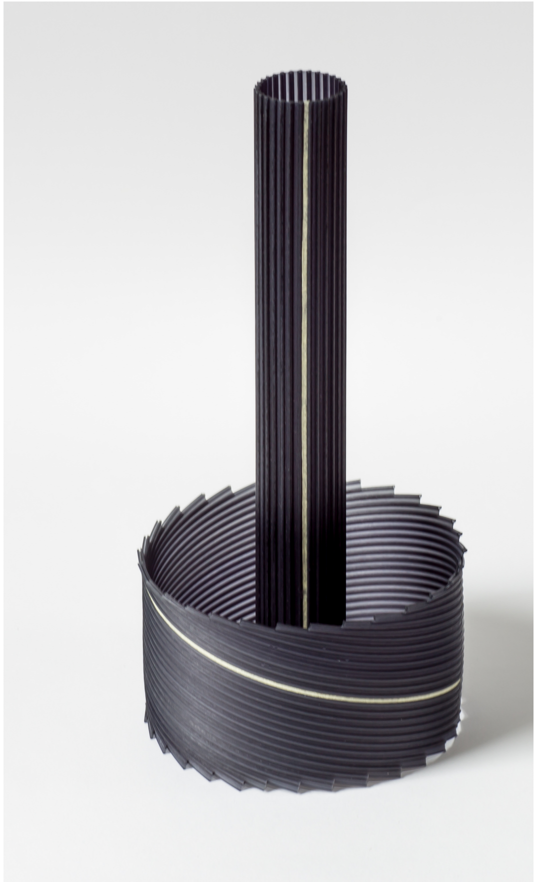
3. Metaboly: how is shape controlled?



Shape control in Euglena

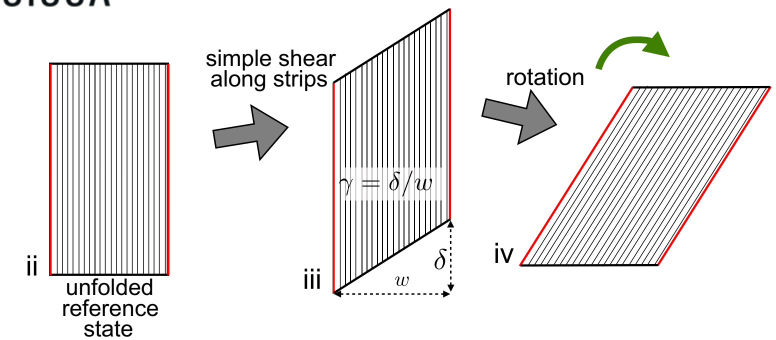






(with G. Noselli, unpublished)

Shape programming (after E. Sharon et al.)



$$(u, v) \mapsto \mathbf{x}(u, v)$$

$$\begin{bmatrix} \mathbf{x}_{,u} \cdot \mathbf{x}_{,u} & \mathbf{x}_{,u} \cdot \mathbf{x}_{,v} \\ \mathbf{x}_{,u} \cdot \mathbf{x}_{,v} & \mathbf{x}_{,v} \cdot \mathbf{x}_{,v} \end{bmatrix} = \begin{bmatrix} 1+\gamma^2 & \gamma \\ \gamma & 1 \end{bmatrix}$$

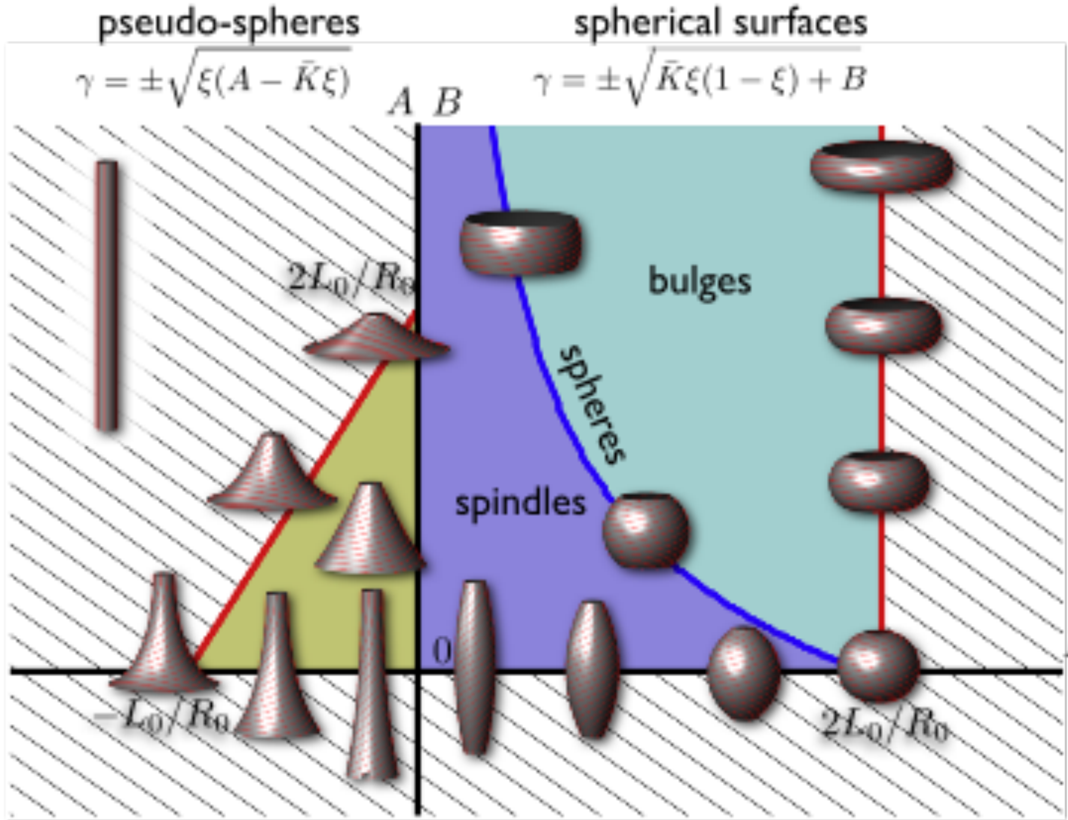
Theorema Egregium (Gauss):

$$\gamma = \gamma(v) \Longrightarrow K = (-\gamma \gamma_{,v})_{,v}$$

$$\gamma = \text{const} \longrightarrow K = 0$$
(cylinders)

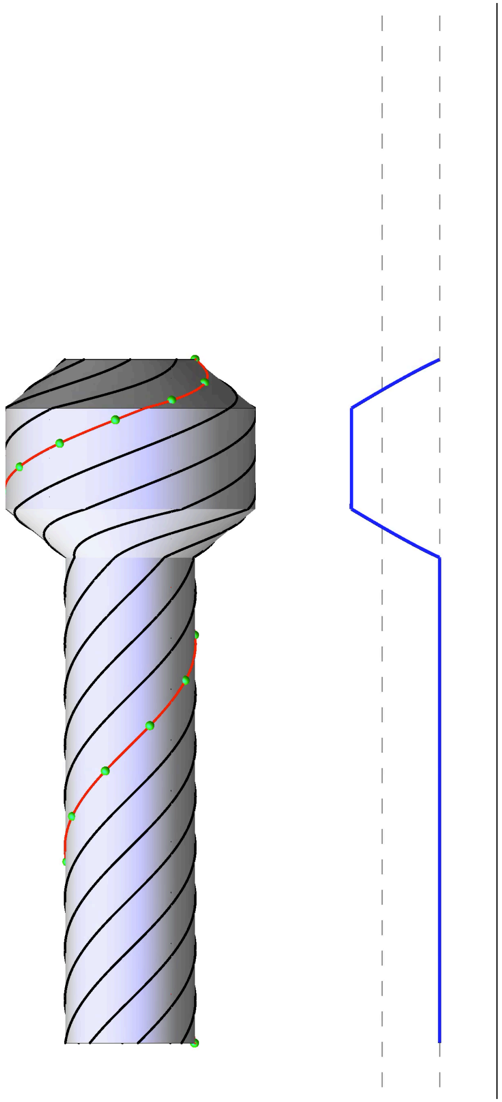
$$\gamma\gamma_{,v} = \text{const} \longrightarrow K = 0$$
(cones)

$$\gamma\gamma_{,v} \neq \text{const} \longrightarrow K \neq 0$$
(spheres, pseudospheres, etc.)

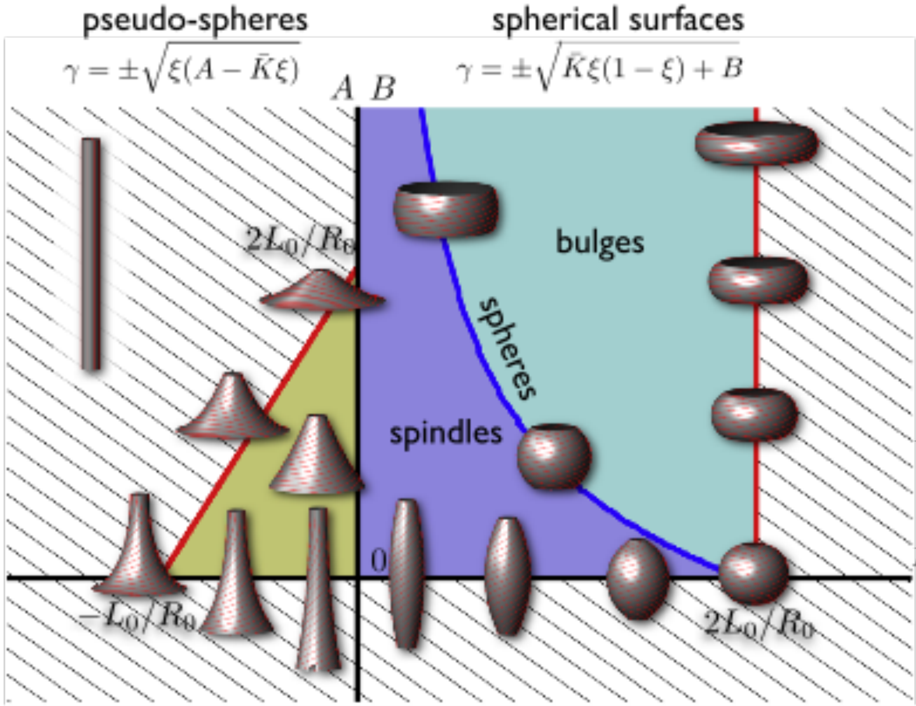


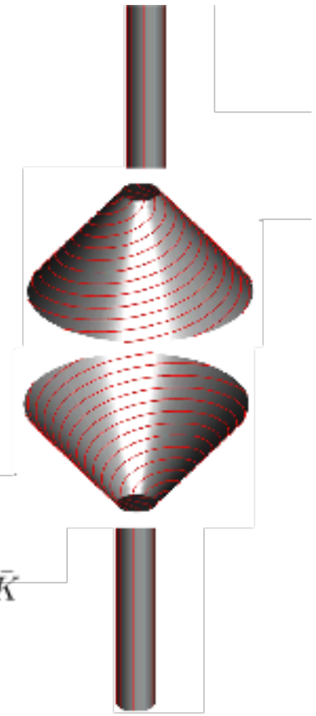
M. Arroyo, ADS, JMPS 62, 99-112

Euglena know Gauss' Thm Egregium



M. Arroyo, ADS, JMPS 62, 99-112

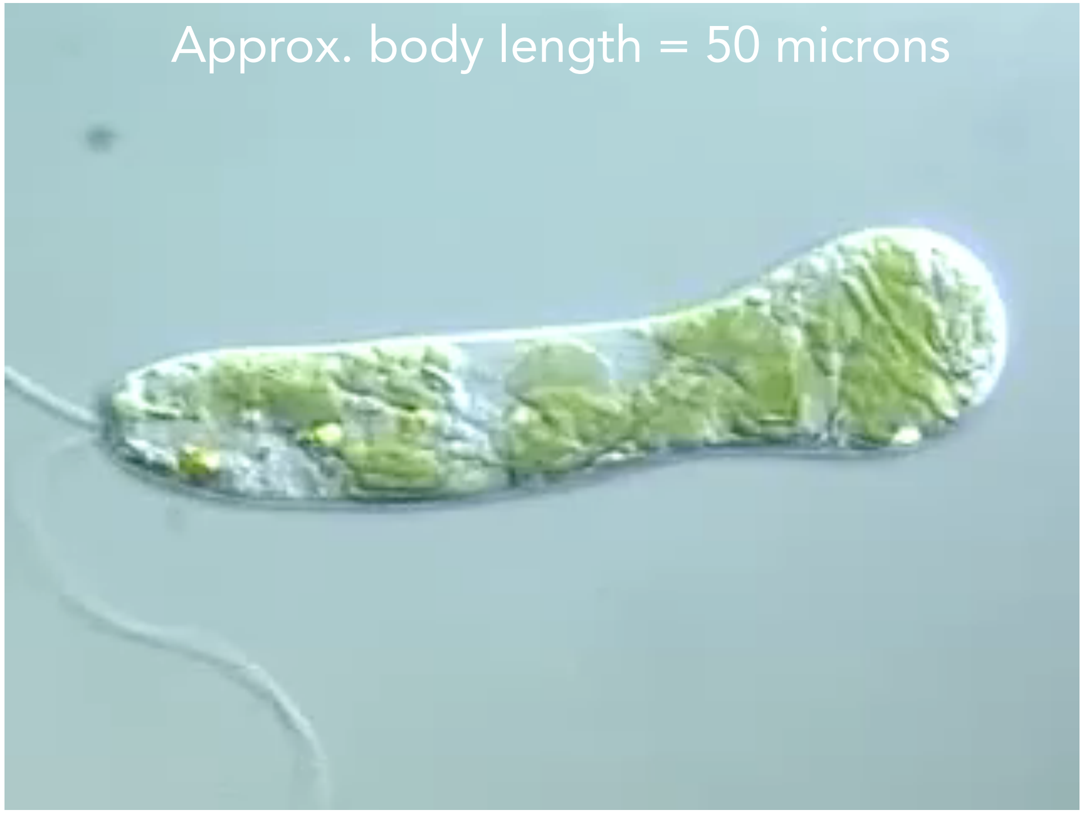




$$K = (-\gamma\gamma_{,v})_{,v}$$

Axisymmetric shear: $\gamma = \gamma(v)$

Euglena: unicellular organism with both flagellar motility and "metaboly"

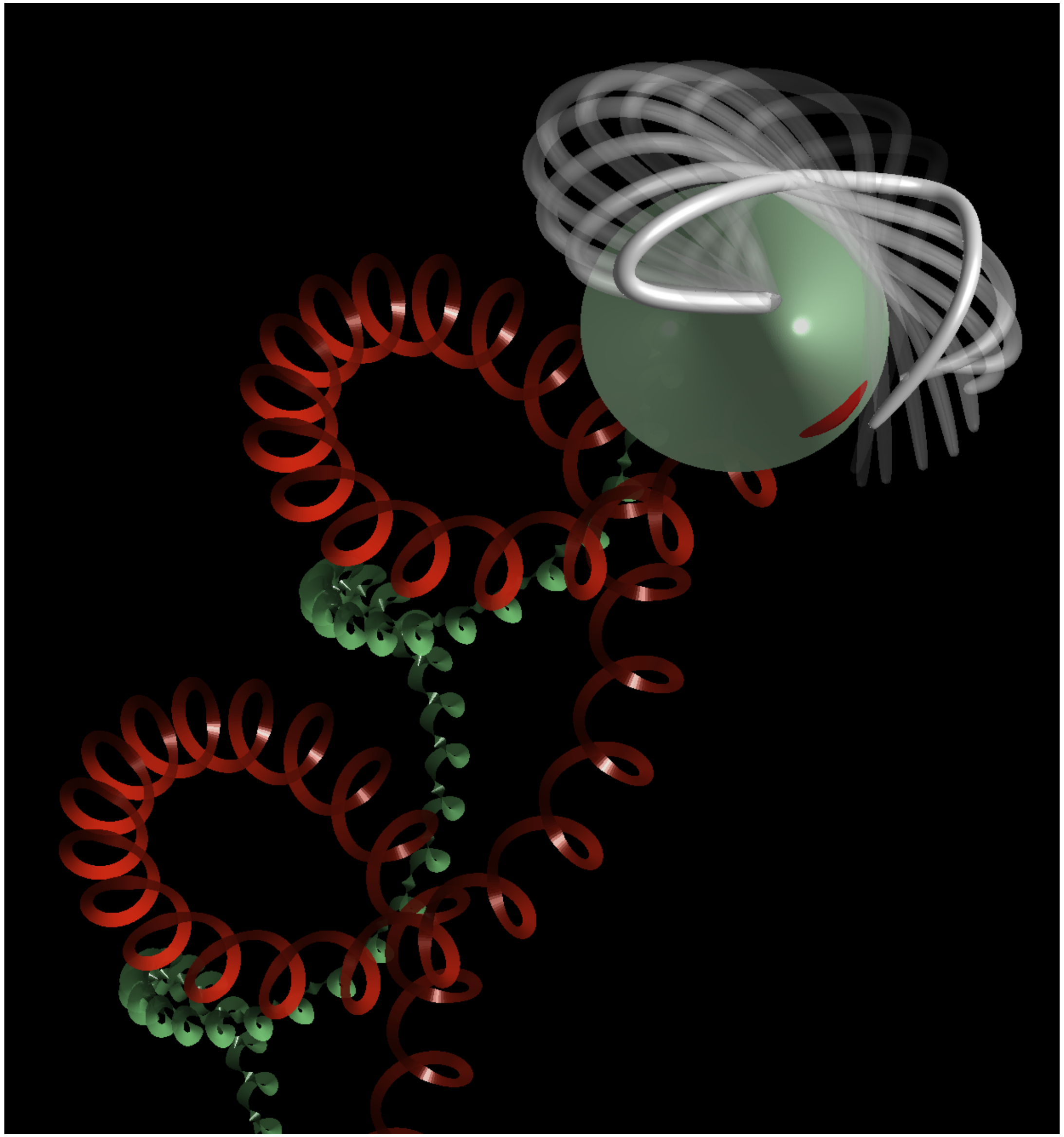


4. What about flagellar propulsion?

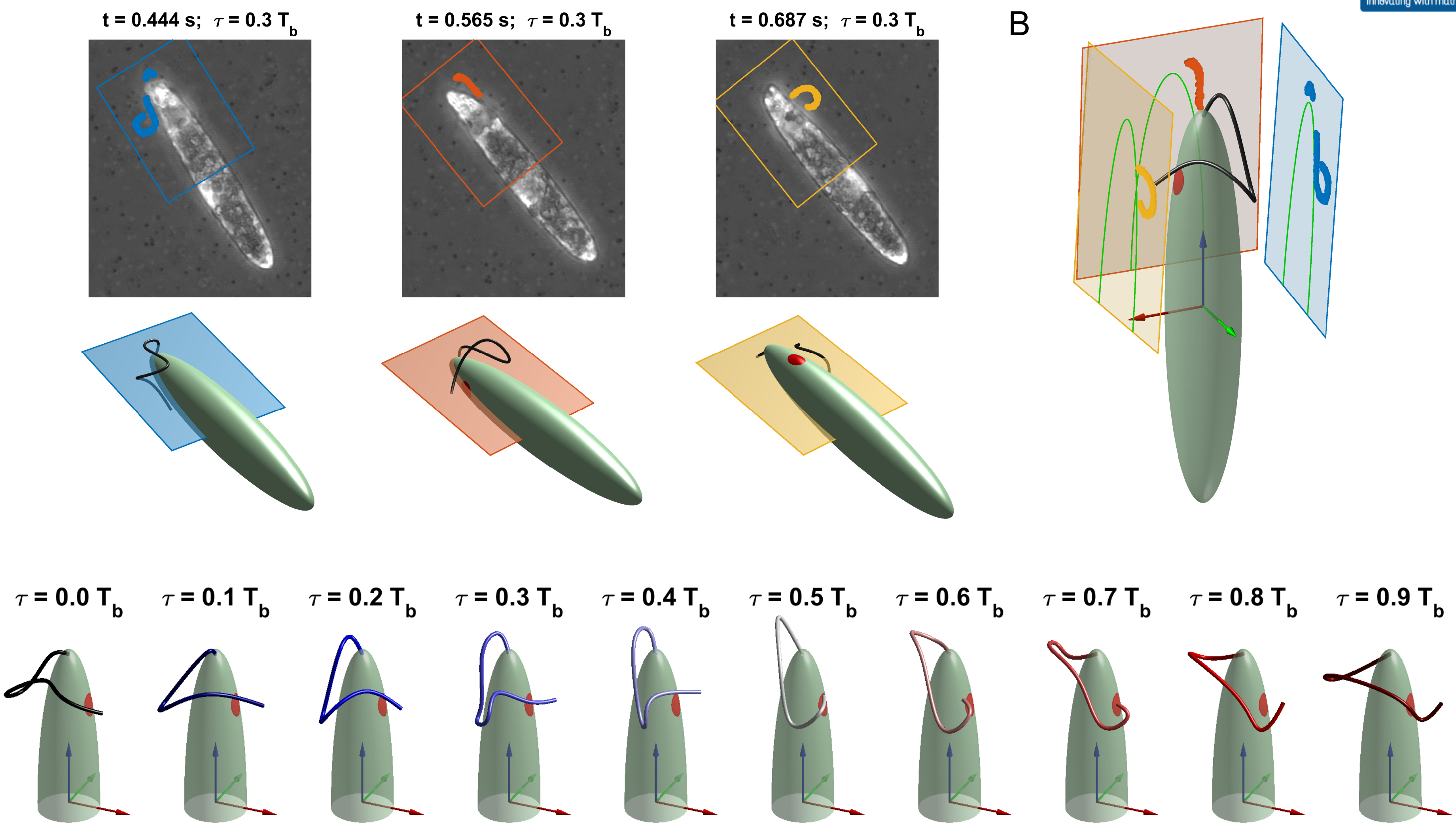
Euglena swimming by flagellar propulsion

2D or 3D?
Reconstruct 3D trajectories and shapes from 2D microscopy?

Orbits of self-propelled flagellates: a universal law



Reconstructing flagellar shapes



M. Rossi, **G. Cicconofri,** G. Noselli, ADS, Kinematics of flagellar swimming in Euglena gracilis: helical trajectories and flagellar shapes, PNAS, accepted.

Two directions we are pursuing

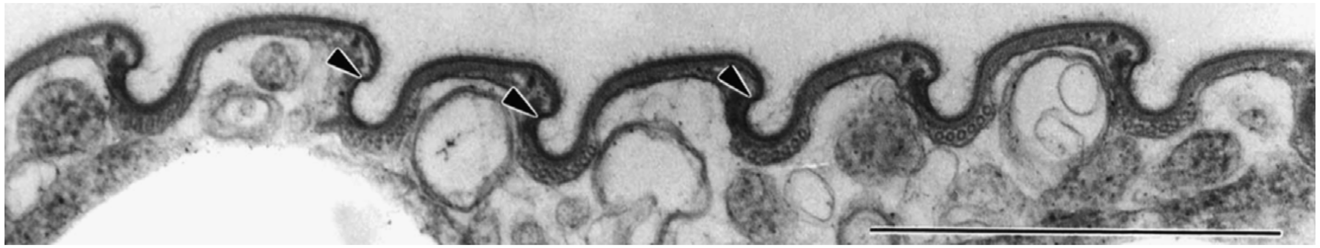
- Euglena: can we mimic their behaviour in artificial, bio-inspired devices ? (Bio-inspired Engineering,…)

(Soft Robotics, Bio-inspired microrobotics, Robo-Physics,…
Surfaces with programmable shapes,…
New smart materials and structures,….)

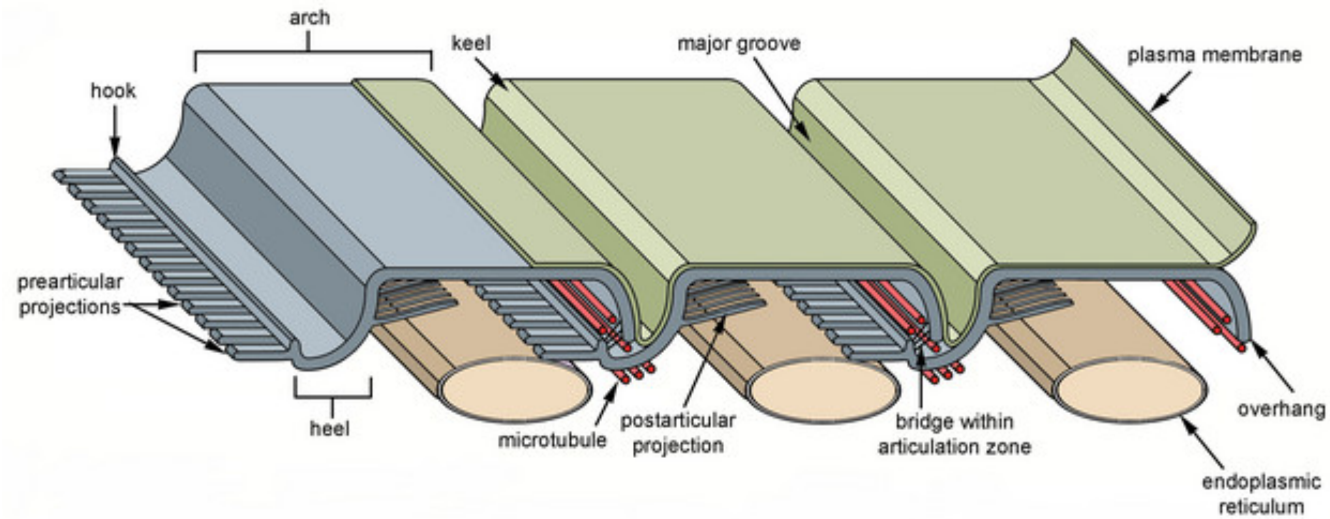
- Euglena: how do they really behave, and what controls their behaviour ? (Biology,…)

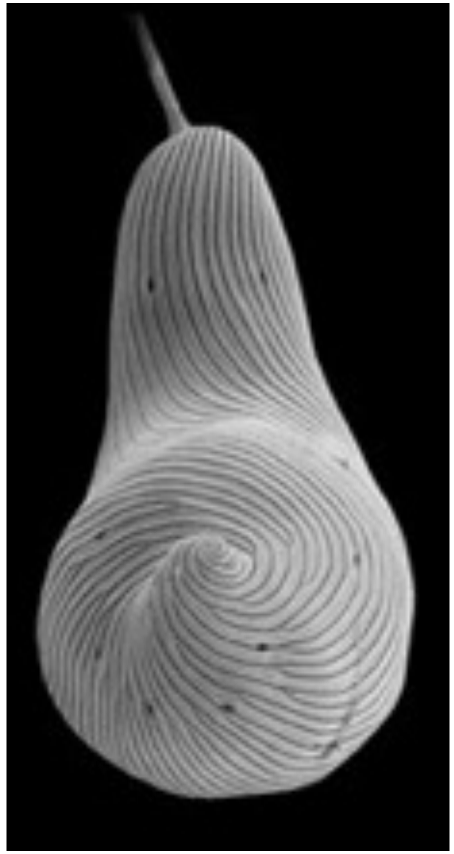
(Microscopic mechanisms for shape control,
Gait switching,…)

Functional hierarchy in actuation: motors > microtubules > pellicle structure



scalebar 2 microns





Pellicle structure provides a subtle balance between structural integrity (stiffness) and readiness to change shape (softness). An instance of morphological computing ?

Summary

ECMTB 2018 LISBON

Celebrating the Year of Mathematical Biology 2018

"Mathematics is Biology's next microscope, only better;
Biology is Mathematics' next Physics, only better." (J.A. Cohen, PLoS Biology, 2004)

Mathematical Euglena

- Mathematical microscopes: lifting of 2D microscopy data to 3D trajectories and flagellar shapes through Helix Thm
- Shape control in Biology and Bioengineering through Gauss' Thm Egregium
- Overarching conceptual paradigms: use of passive elastic properties to "explain" exquisite shape control in unicellular organisms (morphological computing, or control through constraints)

ERC Advanced Grant MicroMotility

Thank you for your attention!

Optimization and Machine Learning

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FIMA
CNR - Roma, October 27, 2017

Table of Contents

Why Machine Learning and Optimization are related ?

Optimization for Machine Learning

- Training a learning machine consists in solving an optimization problem

minimize Prediction error

- standard optimization package may directly apply to ML but exploiting both the nature and the structure of the problem must be considered
- indeed optimization algortihm, when applied to ML, must take into account other aspects rather than only convergence/speed of convergence issues

What is a learning problem ?

Consider a supervised classification problem.

- Given observed input-output pairs (x^p, y^p) with $x^p \in \mathbf{R}^n$, $p = 1, \ldots, P$ (training set)
- Predict unknown output on test data
- It consists in finding a model $f \in \mathcal{F}$ parametrized in $\omega \in \mathbb{R}^d$ such that the prediction error is minimize

A model can be a decision tree, a neural network, a support vector machine, or others

The Expected Error

- For any new sample x, the model gives the output $f(\omega; x)$ and a measure of the error between the true unknown output y and $f(x; \omega)$ is needed
- A loss measure ℓ is used.
- The *Risk* $R(f, \omega)$ is the *Expected Error*

$$\mathbb{E}\{E(x, y; \omega)\} = \int \ell(y, f(x; \omega)) d\mathcal{P}(x, y)$$

- Minimization of the Risk

$$\text{minimize}_{f,\omega} \text{ Expected Error}$$

- The optimization problem is not well-posed in the sense that the objective function is imponderable

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The Empirical Error

Usually a surrogate function is used which measure the error on the known data (training set).

The *Empirical Risk* is the average loss

$$R_{emp}(f,\omega) = \frac{1}{P}\sum_{i=1}^{P} \ell(y^p - f(x^p;\omega))$$

The surrogate optimization problem is considered

$$\text{minimize}_{f,\omega} \text{ Empirical Risk}$$

Given the loss ℓ and the class of functions $\mathcal{F}$ the *Empirical risk* depends only on the available samples

In this case the empirical risk minimization problem reduces to find the optimal parameters

$$\omega^*_{emp} = \arg\min_{\omega\in\mathbb{R}^q} R_{emp}(\omega) = \sum_{p=1}^{P} E_i(\omega)$$

where f_{emp} is chosen.

Tradeoff of ERM[1]

Consider the error

$$\underbrace{R(f^*, \omega^*) - R(f_{emp}, \omega^*_{emp})}_{\mathcal{E}_{app} + \mathcal{E}_{est} + \mathcal{E}_{opt}}$$

- Approximation error: f^* is unlikely to belong to the family $\mathcal{F}$ fron which f_{emp} has been selected; it measures the error due to the choice of the class $\mathcal{F}$;
- Estimation error: it measures the effect of minimizing the $R_{emp}(\omega)$ instead of the expected risk $R(\omega)$ over $\mathcal{F}$.
- Optimization error: it reflects the fact that, when computational time is restricted, algorithms return an approximate solution $\widehat{\omega}$ of $\min R_{emp}$ rather than the optimal one [1].

[1] [Vapnik-Chervonenkis [8], Léon Bottou & Olivier Bousquet, 2008 [1]]

Large-scale supervised machine learning: large P, large q, large n

- P: number of observations
- q: number of parameters
- n: dimension of each observation (input)

For small-scale pb, the computing time is not limited and the optimization error can be reduced to insignificant levels.

$$\underbrace{R(f^*,\omega^*) - R(f_{emp},\omega^*_{emp})}_{\mathcal{E}_{app}+\mathcal{E}_{est}}$$

For large-scale pb, it is important to achieve a given accuracy faster otherwise the term $\mathcal{E}_{opt}$ cannot be neglected.

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Regularized Empirical Risk

The Vapnik-Chervonenkis relationship [8] states that in probability

$$\sup_{f \in \mathcal{F}} |R(\omega) - R_{emp}(\omega)|$$

is bounded above by a function of the complexity of the class $\mathcal{F}$. Minimizing the empirical risk may be misleading. A regularization term is added to R_{emp} in order to "penalize complexity".

Minimization of the Regularized Empirical Risk

$$\min_{\omega \in \mathbb{R}^q} \underbrace{\frac{1}{P} \sum_{p=1}^{P} \ell(f(x^p; \omega) - y^p)}_{\text{loss function}} + \underbrace{\mathcal{R}(\lambda, \omega)}_{\text{regularization term}}$$

The learning paradigm

In order to specify the learning problem:

- choose the class of functions f
- choose the measure of "closeness": loss function ℓ
- choose the regularization term

The regularization term may be not enough to control the risk.
Keep aside a portion of data (test set) to check actual performance.
Find ω^* by optimizing the regularized $R_{emp}(\omega)$ BUT use $R_{test}(\omega^*)$ for checking "goodness" of the solution (model f, parameters ω).

The learning problem

1. Cost functions are averages
2. No need to optimize below statistical error
3. Testing error is more important than training error
4. Avoid underfitting: look for small training error
5. Avoid overfitting: look for small testing error

Linear Support Vector Machine

We focus on SVM

- decision function $f = \text{sign}(w^T x + b)$
- hinge loss function

$$\ell = \max\{0, 1 - y^p(w^T x^p + b)\}$$

- mean square ℓ_2 regularized error

Linear SVM

$$\min_{w,b} \frac{1}{P} \sum_{p=1}^{P} \max\{0, 1 - y^p \cdot (w^T x^p + b)\} + \lambda \|w\|^2$$

The regularization parameter λ must be chosen

Note that a bias term b is present.

If n (number of features) is small, b may be important. Usually b is not used in large-scale linear classification (internet, text).

Linear SVM

The target problem can be easily stated as a convex QP in $q = n + P + 1$ variables.

Soft SVM

$$\begin{aligned}
\min_{w,b,\xi} \quad & \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{P} \xi_i \\
& y^p(w^T x^p + b) \geq 1 - \xi_p \quad p = 1, \dots, P \\
& \xi \geq 0
\end{aligned}$$

- It is the problem of maximizing the margin in the family of affine function with a empirical error (misclassified points $\xi > 1$) which is weighted by the hyper-parameter C
- Convex QP: Duality holds and the dual problem is usually considered for the solution.
- By duality, Kernel trick applies and nonlinear SVM appears naturally

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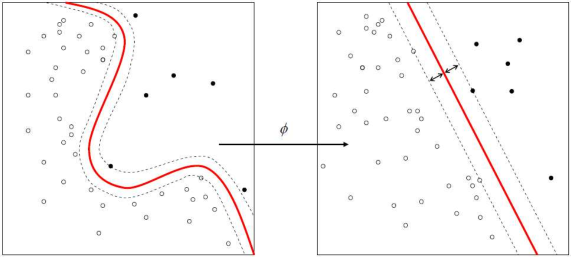
Nonlinear SVM

For better results in classification Nonlinear SVM can be used. In this case classification is done by means of nonlinear separating surface.

The data are mapped nonlinearly in a larger space via $\Phi : R^n \to R^l$, a nonlinearly separating surface in R^p is easily computed by a linear separator in R^l.



By the kernel trick, the transformation Φ is never required.

SVM dual Problem

In practice the quadratic convex dual problem is solved which is written as:

$$\begin{array}{ll} \text{minimize} & f(\alpha) = \frac{1}{2}\alpha^T Q\alpha - \mathbf{1}^T\alpha \\ \\ \text{subj. to} & y^T\alpha = 0, \\ & 0 \leq \alpha \leq \mathbf{1} \cdot C \end{array}$$

- $Q \succeq 0$ with elements $q_{ij} = y^i y^j k(x^i, x^j)$ where $k(x_i, x_j)$ is the *Kernel function* (a scalar product in the transformed space)
- $\mathbf{1} \in R^n$ vector of all 1's, $C \in R$ user selected.
  Choice of "good" C may lead to difficulties.
  Large C may lead to overfitting (bad value of the test error).

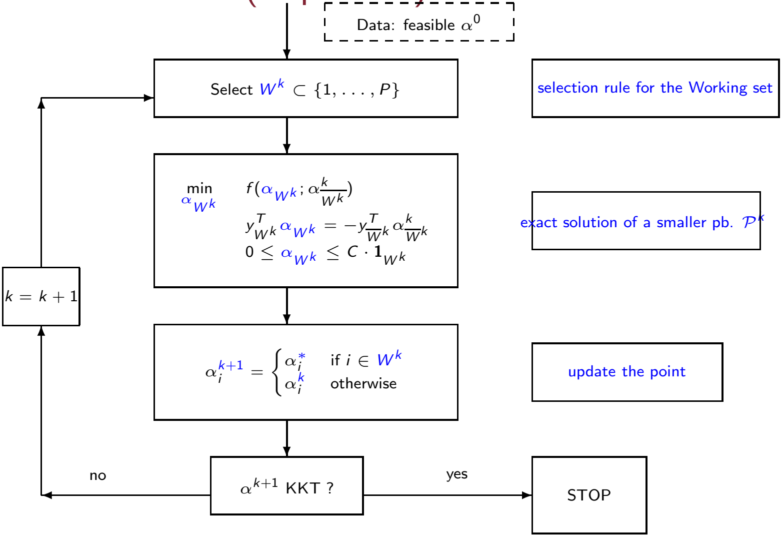
SVM dual problem

- It is a fully dense $P \times P$ quadratic convex programming problem
- The Hessian matrix Q cannot be stored when the dimension of training set P is huge
- Basic operations, such as the gradient updating or the objective function evaluation, are both too time and memory consuming
- Traditional optimization methods cannot be directly employed.
- special structure of the feasible region helps in defining efficient algorithms

Decomposition methods are used

The solution of the original huge problem is obtained by solving a sequence of smaller dimension problems with the same structure of the original one.

Decomposition scheme (sequential)



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Important issues in decomposition methods

From ML perspective

- No need to have very accurate decision function:

$$sgn\left(\sum_{p=1}^{P}\alpha_p^* y^p k(x^p, x) + b\right)$$

  Prediction may still be correct with a rough α

- Computational costs are mainly due to evaluation of the columns of the hessian matrix (kernel evaluations) which appears in gradient updating

$$\nabla f(\alpha^{k+1}) = \nabla f(\alpha^k) + \sum_{i \in W^k} Q_i(\alpha_i^{k+1} - \alpha_i^k)$$

- The number of support vectors (nonzeros in α^*) $<< P$ (training size).
  It may happen that starting with $\alpha^0 = 0$, some instances are never used (shrinking techniques may be used)

Important issues in decomposition methods

From optimization perspective

- The size of W^k affects efficiency of the solution of subproblems.

`How many ?`

- Theoretical convergence properties depends from the rule for selecting the working set:

W^k cannot be chosen arbitrarily

`Which ones ?`

HOW MANY ?

The size of W^k

- $|W^k| = 2$
- Sequential Minimal Optimization (SMO)
- analytic solution α^*_W
- fast inner iteration
- larger number of outer iterations

- $|W^k| > 2$
- Usually $|W^k| = 10$
- iterative solver required
- slower inner iteration
- smaller number of outer iterations

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Selection rule

To obtain convergence properties, indexes cannot be inserted in W^k as we want, BUT

MUST satisfy some rules.

Most convergent methods select indexes in the working set according to a rule tied to the violation of the Karush-Kuhn-Tucker (KKT) conditions.
When $|W^k| = 2$ this choice corresponds to the Maximal Violation Pair rule

Other rules may include second order information in the local model [current version of LIBSVM [2]] or use cyclic ordering of the indexes [4].

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Caching tecniques

In huge problems when the whole kernel matrix cannot be stored, a fraction of the memory (cache) is used to

store the most recently used hessian columns

If the indexes selected to enter the working set are already in the cache, the corresponding hessian columns need not to be re-calculated

Dynamic update of elements in the cache

when the cache is full, older elements are removed

Caching and selection rule

To reduce the computational time it is convenient to select W^k containing elements corresponding to columns store in the cache in order to

saved Kernel computations.

However the rule that guarantees convergence properties (MVP or the more general rule)

may not allow to exploit information in the cache

How to combine SMO-type and caching strategy ?

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Convergence issues

Most of the proofs of convergence of SMV algorithm relies on the analysis of sequence "compared" to the sequence generated by the MVP rule. Indeed α^k_{MPV}, solution of subproblem $\mathcal{P}^k$ when W^k includes the two MV indeces, and the corresponding objective function value $f^k_{MPV} = f(\alpha^k_{MPV})$ may play a significant role.
As an example in [Lucidi, P.; Risi, Sciandrone 2009 [5]] an hybrid algorithm is proposed in which f^k_{MPV} is used as a reference value at each iteration. Providing that α^k_{MVP} is not at the lower or upper bounds, any point satisfying

$$f(\alpha^{k+1}) \leq f^k_{MPV} - \tau \|\alpha^{k+1} - \alpha^k_{MVP}\|^p$$

can be accepted.

$\boxed{\text{large degree of freedom in the choice of } \alpha^{k+1}}$

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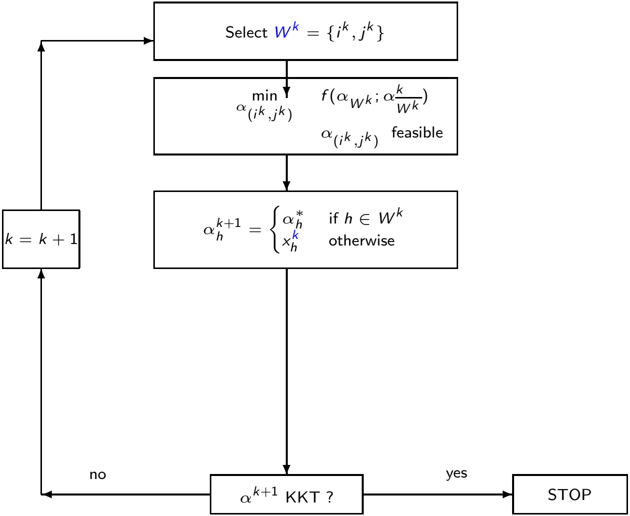
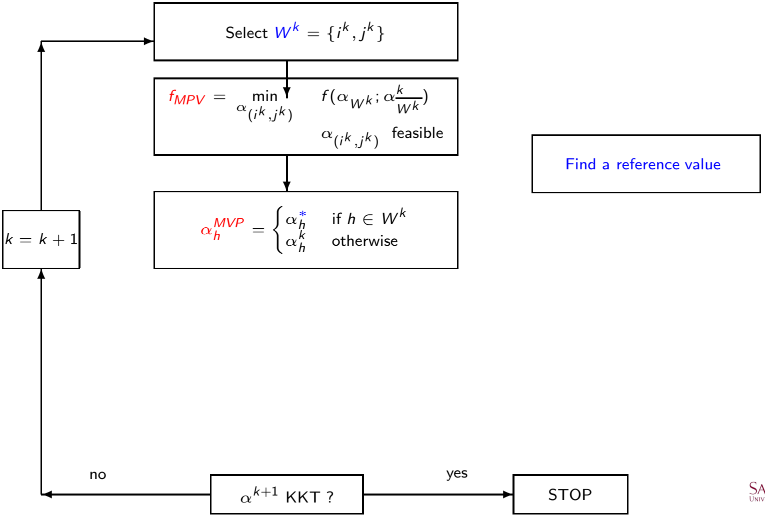
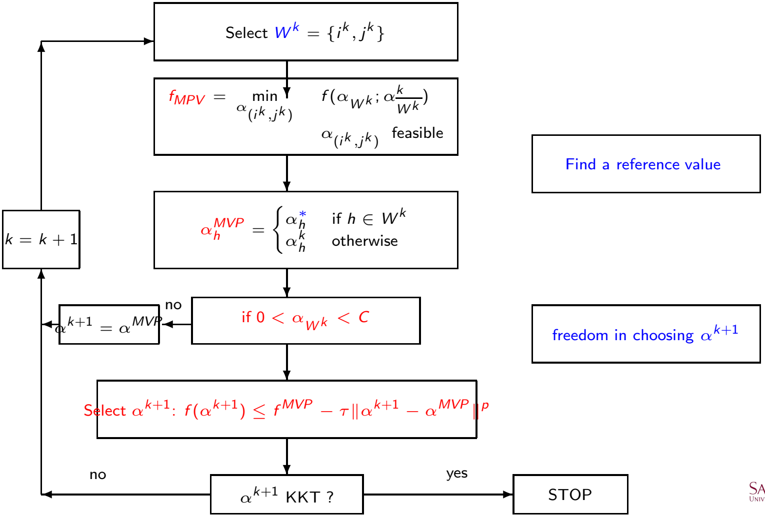
Hybrid Decomposition scheme



Hybrid Decomposition scheme



Hybrid Decomposition scheme



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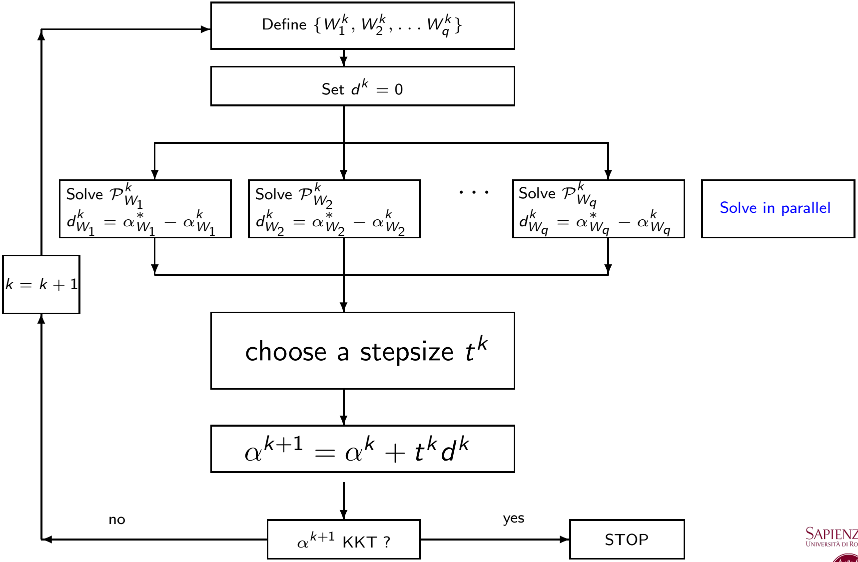
MVP, Caching and distributed architecture

- Parallel and distributed architecture [Jacobi type in [3]]
- Faster decrease of accuracy
- Exploiting SMO-type features

In [Manno, P., Sagratella [6]] a different framework for parallelize decomposition methods

Decomposition scheme (parallel)



Convergence to an optimal solution

How to select blocks W_j^k?

descent block needed

How to compute stepsize t^k?

- Exact linesearch (analytic)
- Diminishing stepsize

$$t^k \to 0 \qquad \text{and} \qquad \sum_{k=0}^{\infty} t^k = +\infty$$

Other technical aspect: use of a proximal point modification when needed ($\tau > 0$)

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Descent iteration

Descent block

Given a feasible point α^k and $\epsilon > 0$, we say that block of variables $W_i \subseteq \{1, \ldots, n\}$ is a *descent block* at α^k if it satisfies

$$\|\alpha^*_{W_i} - \alpha^k_{W_i}\| \geq \epsilon \|\alpha^k_{MVP} - \alpha^k\|$$

- α^k_{MVP} is a solution obtained by using the MVP selection rule
- We say that k is a *descent iteration* whenever at least one descent block W_i is selected among blocks at iteration k

How to define a descent block?

Simplest way is to select the most violating pair in one of the blocks (but it can be relaxed)

Convergence conditions

Set $\tau_i^k > 0$ if subproblem i is not strictly convex

Cond.1

- Exact LS
- a descent iteration within a fixed number of its

Cond. 2

- Diminishing stepsize
- Every iteration is descent

Cond 3

- Diminishing stepsize
- a descent iteration within a fixed number of its
- $\{t^k\}$ is monotone non increasing

A simple implementation

SMO-type implementation

- The $\varepsilon-$MVP always selected (block W_1^k)
- Blocks $|W_i| = 2$ with $i = 2, \ldots, q$
- $2 \cdot q$ components updated at each iteration
- Analytic stepsize
- Fast gradient update

Blocks are selected among the $\varepsilon-$ most violating pairs.
A Cache version selects blocks $i = 2, \ldots q$ within the cache.

Test problems

name	#features	#training data	C	kernel type	cache
a9a	123	32561	1	gaussian	500
gisette	5000	6000	1	linear	500
cod-rna	8	59535	1	gaussian	500
real-sim	20958	72309	1	linear	500
rcv1	47236	20242	1	linear	500
w8a	300	49749	1	linear	500

Table : Training problems description.

The relative error RE is considered

$$\mathrm{RE} = \frac{f^* - f}{f^*}$$

where f^* is the known optimal value

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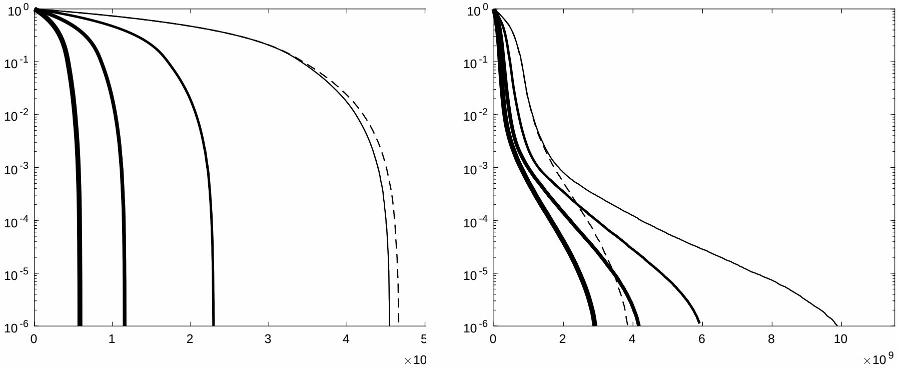
RE versus kernel evaluations

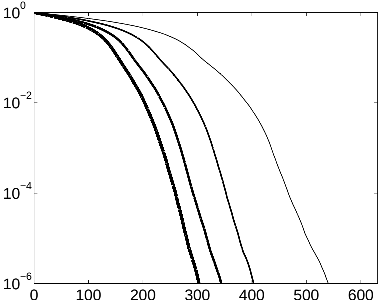
Just two examples (others has similar behaviour) (a9a and cod-rna)



We compare increasing values of pairs q:

- $q = 1$ LIBSVM first order and second order (dashed line) selection rule
- $q = 2, 4, 8$ (increasing thickness of the line)

RE versus time (cache version)



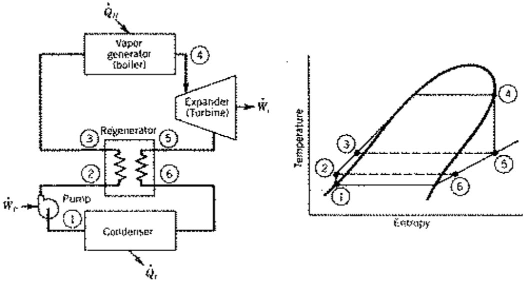
Why Machine Learning and Optimization are related ?

Machine Learning for Optimization

- Often the analytic expression of the functions involved in the optimization problem are not known (grey/black-box optimization)
- ML model may help for obtaining well behaved surrogate models to be used to improve precision and efficiency

Consider the Organic Rankine Cycle (ORC) system for waste heat recovery application.
[Massimiani,P., Sciubba, Tocci [7]]

Neural networks for small scale ORC optimization[2]



- it is a highly non-linear optimization problem
- the analytic form of the objective function and constraints not available (black box algorithms)
- free derivative algorithms, genetic algorithms, etc.

[2] Entropea LABS

ORC optimization problem

- Use FNN to build a surrogate models of objective and constraints
- Use standard algorithm for the optimization
- More reliable results and reduced computational time with respect to black box optimization algorithms

The maximization of the power output of the ORC system has been performed.

Decision Variables

Working fluid mass flow rate
Bottom/top pressure of the ORC cycle
Super-heating rate $T_5 - T_4$
Turbine efficiency
Degree of regeneration $\frac{h_6 - h_9}{h_6 - h_7}$

The mathematical model

$$\max_{\mathbf{x} \in \Omega} \quad (P_{turbine} - P_{pump}) = P_{cycle}$$

subject to

no violation of the 2nd law of thermodynamics
no deteriorations of fluid
Technical constraints

Results

The use of a Neural Network model gives

- performance slightly better (similar) to commonly used optimization algorithms
- faster computational time of the ORC optimization process
- Allow to include other constraints (Thermo-economic optimization)

Conclusion

Optimization for Machine Learning

- Special properties of SVM contribute to the viability of decomposition methods
- This is true also for other ML models
- A lot to do for new architecture (deep networks, Recurrent networks, Long short-term memory ecc.)

Machine Learning for Optimization

- Use of ML may help in difficult engineering problems to get reliable models, useful for both applying algorithm and to check behaviour of complex systems

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Thank you for your attention

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Big Data and Networks for Fraud Detection in the Insurance Sector

Michele Tumminello, Andrea Consiglio
Department of Economics, Management and Statistics
University of Palermo

Summary

- The Integrated Antifraud Archive
- Bipartite Networks and statistically validated networks
- Network indicators
- Criminal specialization and network motifs
- Conclusions

Big Data: The Integrated Antifraud Archive (AIA)

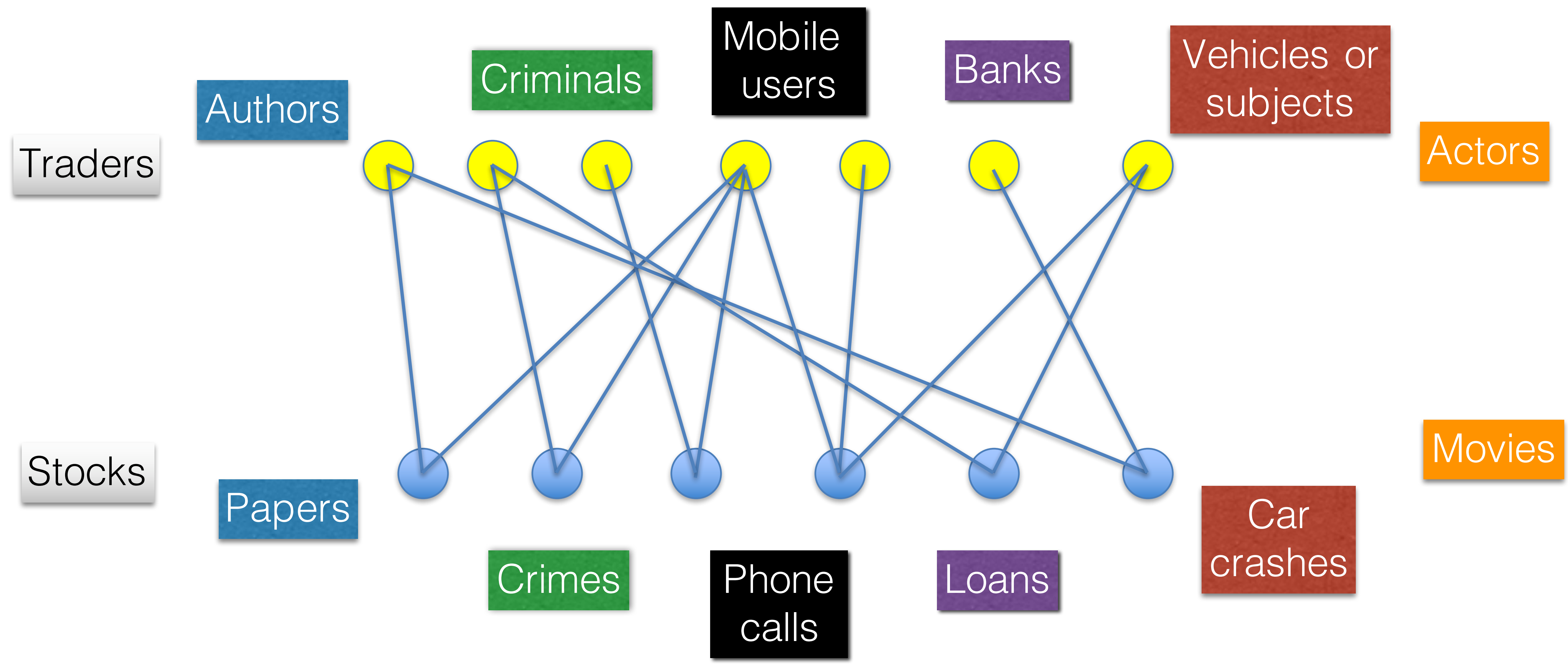
- Time period: 2011-2016
- About 14 million car accidents
- About 20 million individuals and companies
- About 18 million vehicles

Tumminello M, Consiglio A, **Project**: "*Network analysis and modelling of the integrated anti-fraud database*", funded by the Istituto per la Vigilanza sulle Assicurazioni (**IVASS**), which is the National Agency that supervises the activity of all the insurance companies operating in Italy. Responsible for IVASS: **Farabullini F**

Objectives

- Uncover patterns in the data that suggest fraudulent activity.
- Identify organized groups of perpetrators.

Bipartite networks



NJP 2012 QF 2015

Plos ONE 2013

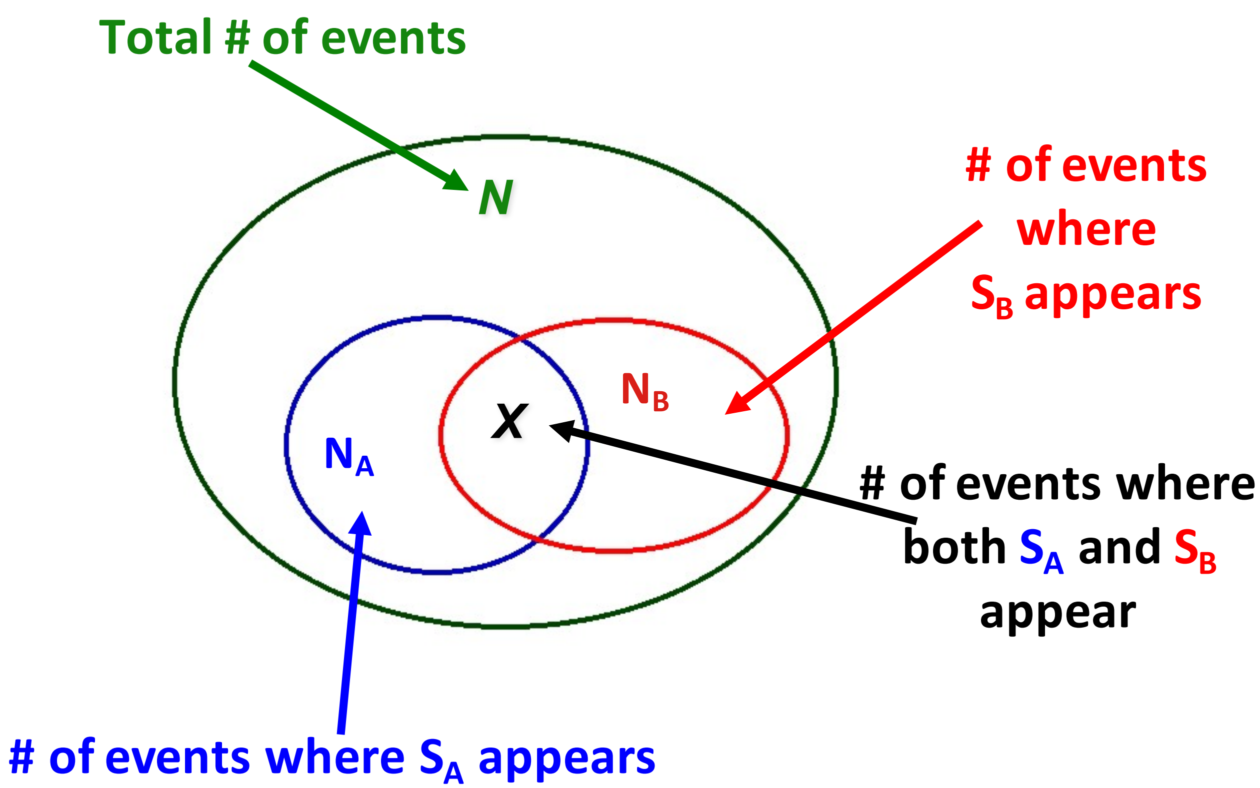
NJP 2015 Sci Rep 2015

QF 2015 JEDC 2015

Plos ONE 2011

A statistical validation of co-occurrence

Suppose there are **N** events in the investigated set. We want to statistically validate the co-occurrence of subject $\mathbf{S_A}$ and subject $\mathbf{S_B}$ in **X** events against a null hypothesis of random co-occurrence. Suppose that the number of events where $\mathbf{S_A}$ ($\mathbf{S_B}$) appears is $\mathbf{N_A}$ ($\mathbf{N_B}$), whereas the number of events where both $\mathbf{S_A}$ and $\mathbf{S_B}$ appear is ***X***.



The question that characterizes the null hypothesis is:
what is the probability that number X occurs by chance?

Tumminello M, Miccichè S, Lillo F, Piilo J, Mantegna RN (2011) Statistically Validated Networks in Bipartite Complex Systems. PLOS ONE 6(3): e17994. doi:10.1371/journal.pone.0017994 http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0017994

Hypergeometric distribution and Statistically Validated Networks

p-value associated with a detection of co-occurrences ≥ X: $$p = \sum_{i=X}^{\min(N_A,N_B)} \frac{\binom{N_A}{i}\binom{N-N_A}{N_B-i}}{\binom{N}{N_B}}$$

- Count the total number of tests: *T*
- Arrange *p-values* in increasing order.
- Set a link between two vertices if the associated p-value satisfies one of the following inequalities

Bonferroni correction : $p-value_{(k)} < \frac{\alpha}{T}$ → **Bonferroni Network**

Holm-Bonferroni correction : $p-value_{(k)} < \frac{\alpha}{T-k}$ → **Holm-Bonferroni Network**

FDR correction : $p-value_{(k)} < \frac{\alpha\, k}{T}$ → **FDR Network**

Type I error control: false positive links

Proposition: the probability that a false positive link is set in the **Bonferroni network** is smaller than α .

Co-occurrences might be dependent

Bonferroni network

- It's the most conservative statistically validated network
- The threshold is independent of p-values
- A **co-occurence** equal to **1** is not statistically significant, provided that the number of links, E, in the co-occurrence network is larger than the number of nodes, N, in the projected set, times α

$$p - value(n_{AB} = 1, N_A, N_B, N) \geq p - value(n_{AB} = 1, 1, 1, N) = \frac{1}{N} > \frac{\alpha}{E}$$

Distinguishing between subjects and vehicles

	Nodes	Links	Connected components (CC)	Size of largest CC
Bonferroni network of **subjects***	1,197,055	1,113,389	407.552	**318,876**
Bonferroni network of **vehicles***	209,801	121.253	99,373	**11**

*Subjects and vehicles recorded in the white list have been excluded from the analysis

Bonferroni network of subjects: largest communities

Community ID	Years over-expressed	Regions over-expressed	Provinces over-expressed
1	2015, 2016	SARDEGNA, LOMBARDIA, LAZIO	VA, TV, TP, TO, SS, RM, RN, RG, PO, PT, PE, PV, PD, MI, LO, LC, LT, CO, CL, CA, BG, MB, OG, VI, VR, AG
2	2011, 2012	CAMPANIA*, NA	NULL, SA, AV, NA, CE
3	-	TOSCANA*, NA	NULL, SI, PO, PT, PI, AR, LU, FI
4	-	PIEMONTE*, VALLE_D'AOSTA	VC, TO, AT, AO, CN, BI
5	-	BASILICATA, PUGLIA*, NA	NULL, BA, TA, PZ, MT, FG, BR, BT
6	-	FRIULI_VENEZIA_GIULIA, VENETO*	VE, UD, TV, RO, PN, PD, FE, VI, VR, BL
7	-	SICILIA*	TP, PA, AG
8	-	LAZIO*	RM, RI, LT, VT
9	-	SICILIA*, NA	NULL, SR, RG, ME, EN, CT, CL
10	-	EMILIA_ROMAGNA*	RN, RA, OR, MO, FC, FE, BO
11	2015, 2016	LAZIO*	RM, RI, LT, FR, VT
12	2011	FRIULI_VENEZIA_GIULIA, VENETO	VE, UD, TV, PN, PD, NO, GO, VI, BL
13	-	LIGURIA, NA	NULL, SV, SP, IM, GE, AL
14	-	LAZIO, NA	NULL, RM, LT, VT
15	2015	CAMPANIA*	SA, AV, NA, CE
17	-	EMILIA_ROMAGNA*, NA	NULL, RE, PR, MO, MN, FE, BO
23	2016	LOMBARDIA	VA, PV, MI, LO, LC, CR, CO, BG, MB
25	-	LOMBARDIA, NA	PC, MN, LO, CR, BS, BG, VR

Are links robust to time-space localization?

*Homogeneity larger than 90%

An indicator of link-robustness to localization

T=total number of events in the dataset (**T**=13,533,500 in AIA 10/2016)

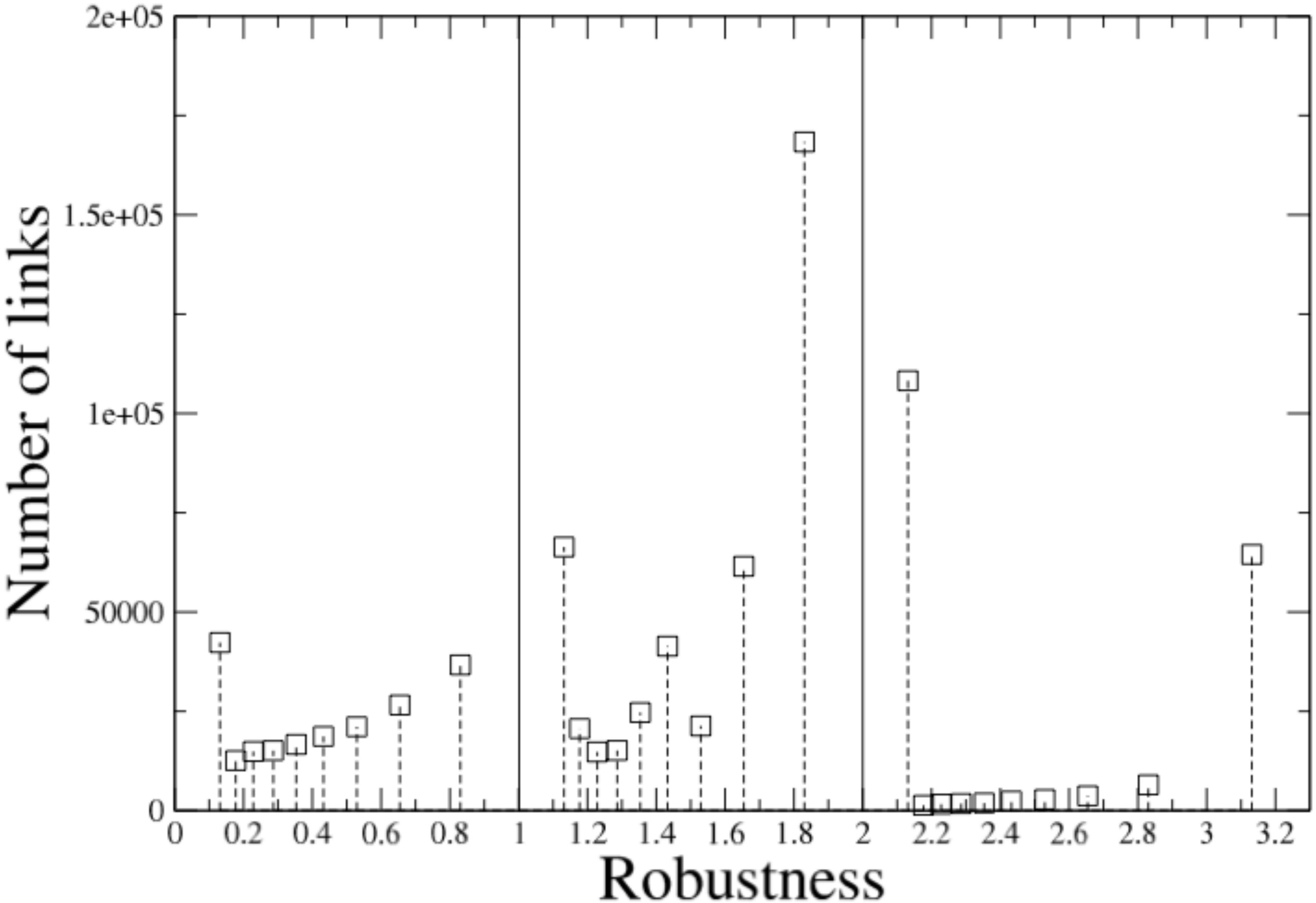
B=bonferroni threshold in the dataset (**B**=1.356e-10 in AIA 10/2016)

M(i,j)=Min(Q) such that p-value(n(i),n(j),n(i,j),Q)<**B**

Robustness indicator

$$R(i,j)=\log_{10}(T)-\log_{10}(M)$$

Bonferroni network: distribution of link-robustness (R>0.1)



Node
(event, subject, vehicle)
indicators

Subject (or vehicle) indicators

Link robustness R can be used to construct an indicator of node relevance and/or centrality

Subject strength: $s(i) = \sum_{j=1}^{N(i)} R_{i,j}$

Subject average strength: $as(i) = \frac{\sum_{j=1}^{N(i)} R_{i,j}}{N(i)}$

(relevant, weighted, and fast)

Subject betweenness: $b(i) = \sum_{p,q} \frac{\sigma_{p,q}(i)}{\sigma_{p,q}}$, where $\sigma_{p,q}$ is the number of shortest paths between p and q and $\sigma_{p,q}(i)$ is the number of those passing through i.

(relevant, unweighted, slow)

Event indicators

For any event ***e,*** the list ***L(e)*** of subject pairs with a validated connection “enhanced” by event ***e*** is compiled.

Event strength: $s(e) = \sum_{(i,j)\in L(e)} R_{i,j}$

(relevant, weighted and fast)

Event betweenness: relevant, but unfeasible in practice (best guess)

Mixed Event-subject indicators

Statistically Validated Bipartite Network

Construction: given the SVN of subjects (or vehicles), a bipartite network is reconstructed by

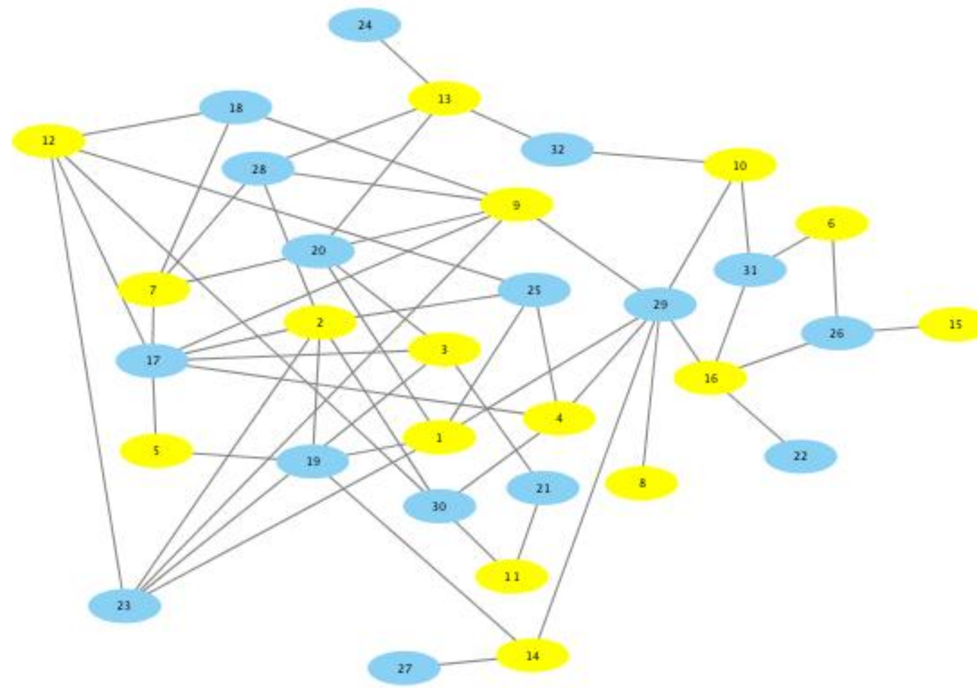
- selecting from the original bipartite network all of the ***event(i)-subject(j)*** pairs such that ***event(i)*** contributed to a **link in the SVN between *subject(j)*** and (at least) another subject.

- adding afterwards all of the subjects directly involved in the selected events.

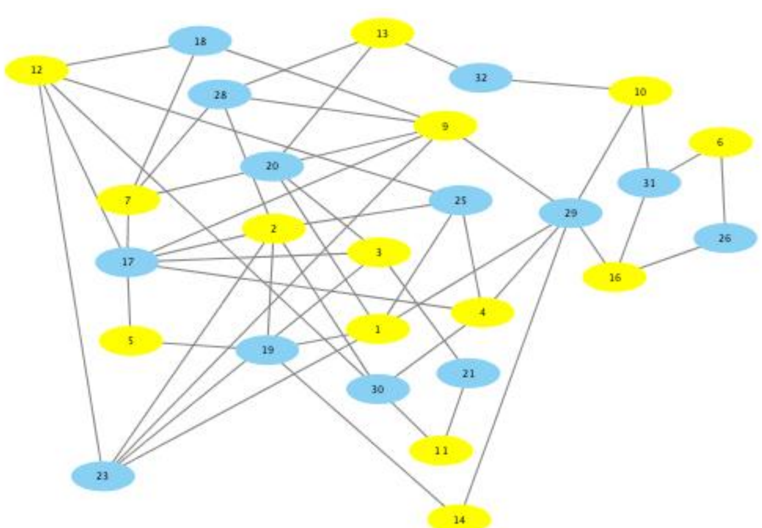
K-H core of a bipartite network

The K-H core of a bipartite network is the largest bipartite **subnetwork** such that nodes of Set A have degree at least K and nodes of set B have degree at least H.

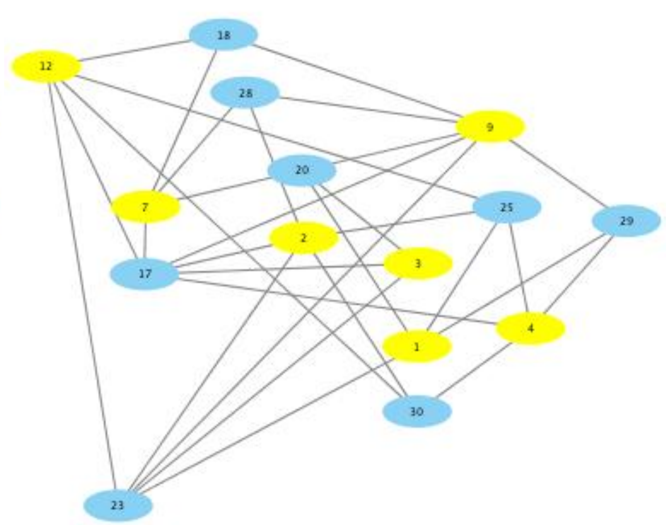
Bipartite network
kids-toys



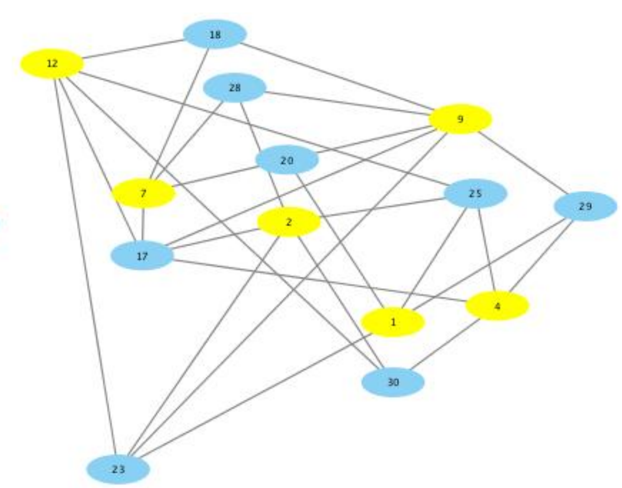
2-2 core



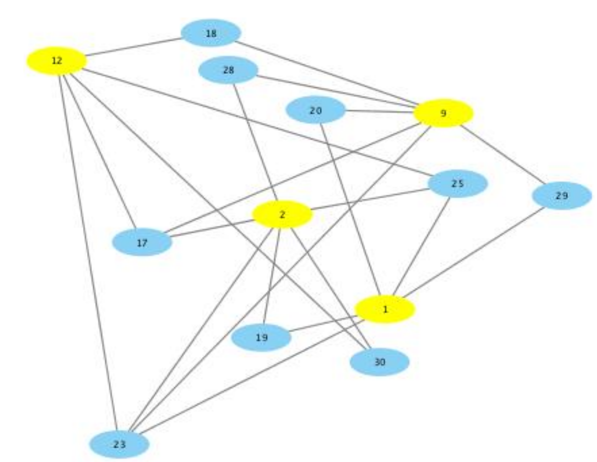
3-3 core



4-3 core



5-2 core



Network indicators: Mixed event-subject indicators of centrality: the **K-H core**

- Event oriented event-subject indicator:

$$KH_e(e,s) = \max(K) \text{ such that } (e,s) \in K - H \text{ core}$$

- Subject oriented event-subject indicator:

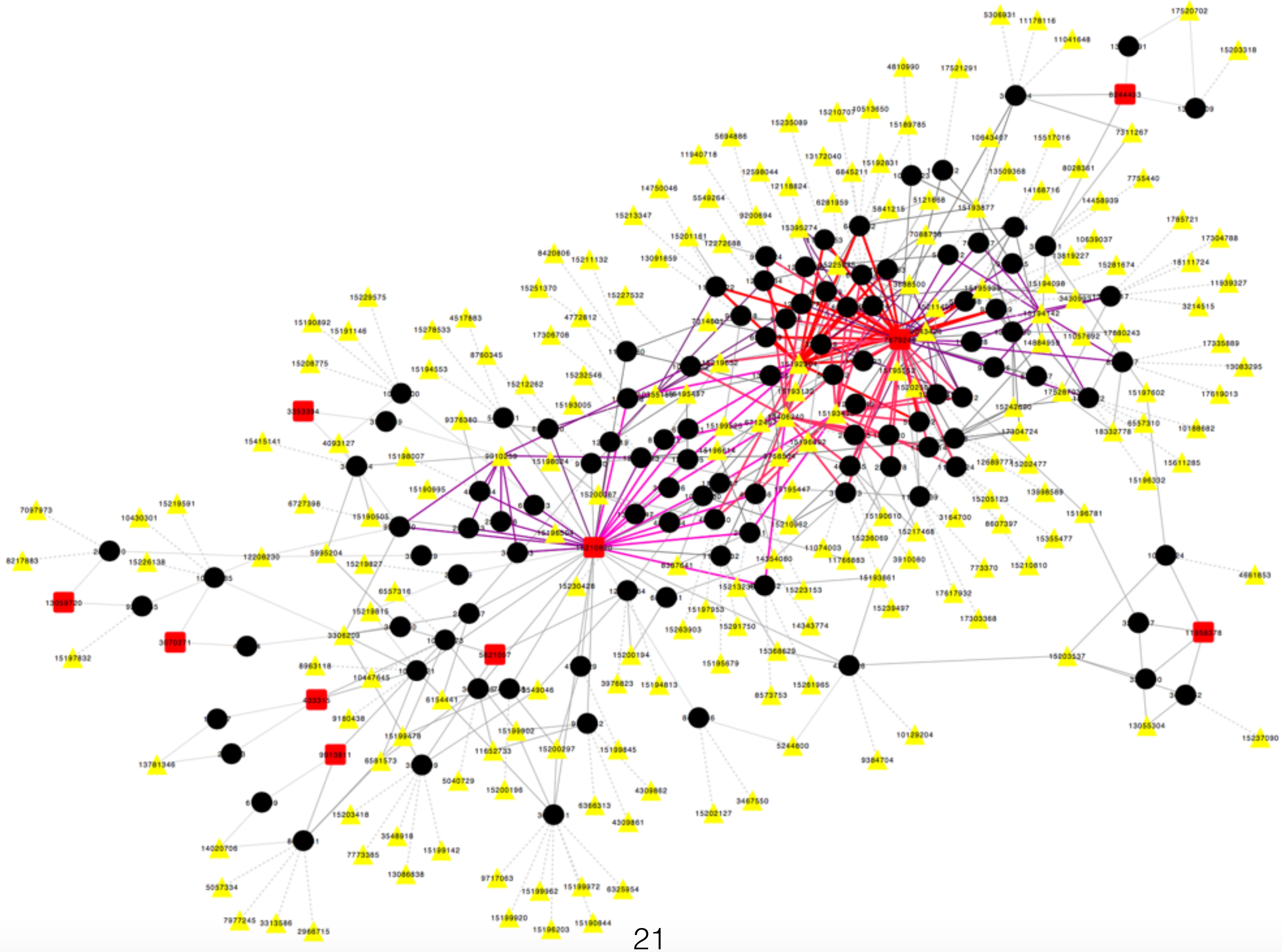
$$KH_s(e,s) = \max(H) \text{ such that } (e,s) \in K - H \text{ core}$$

- Balanced event-subject indicator:

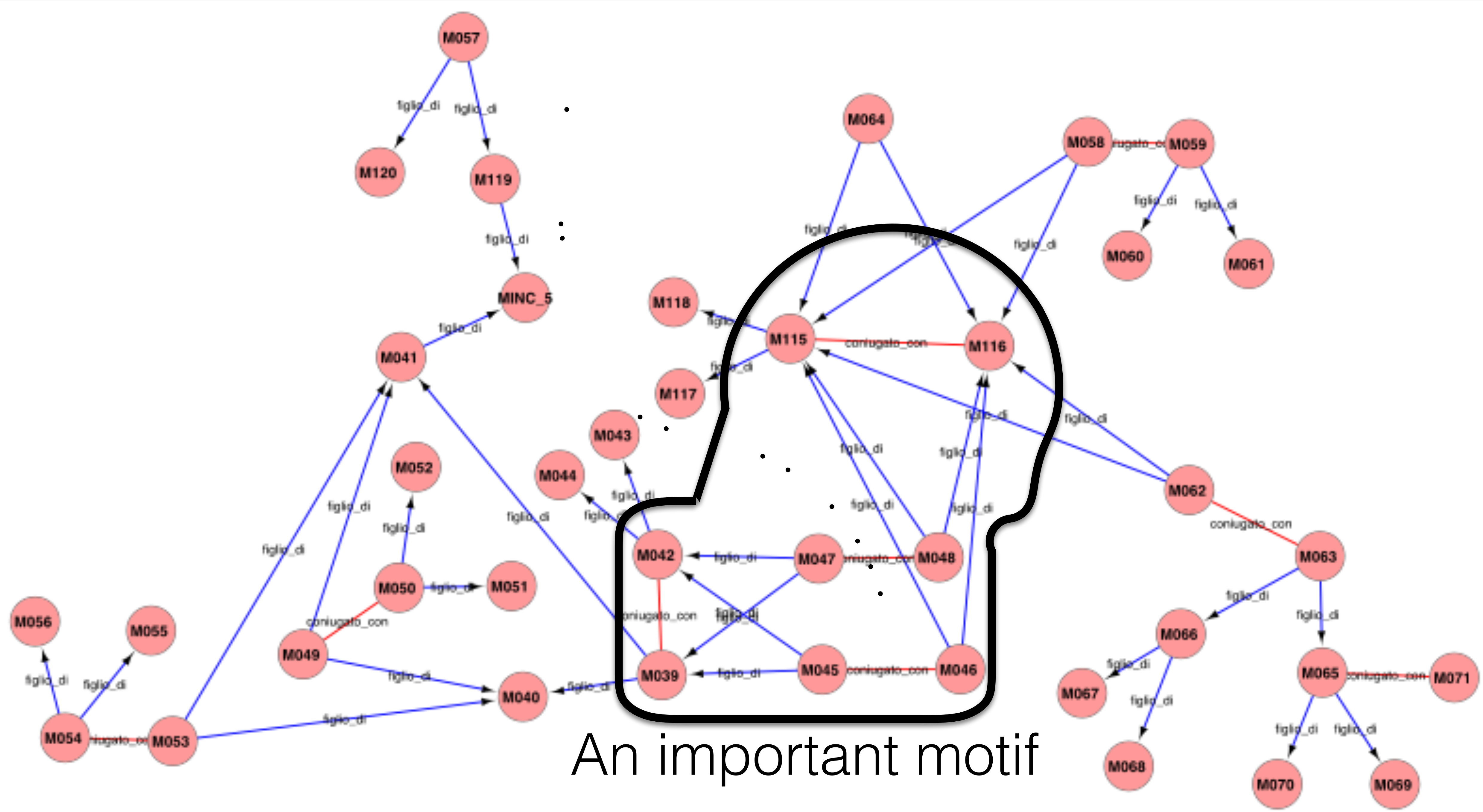
$$KH(e,s) = \max(\sqrt{K \cdot H}) \text{ such that } (e,s) \in K - H \text{ core}$$

K-H CORE DECOMPOSITION

of a real statistically validated bipartite subnetwork



Relevant microstructures: a network of two families
(in collaboration with Procura della Repubblica di Palermo)



Motifs: the heuristics

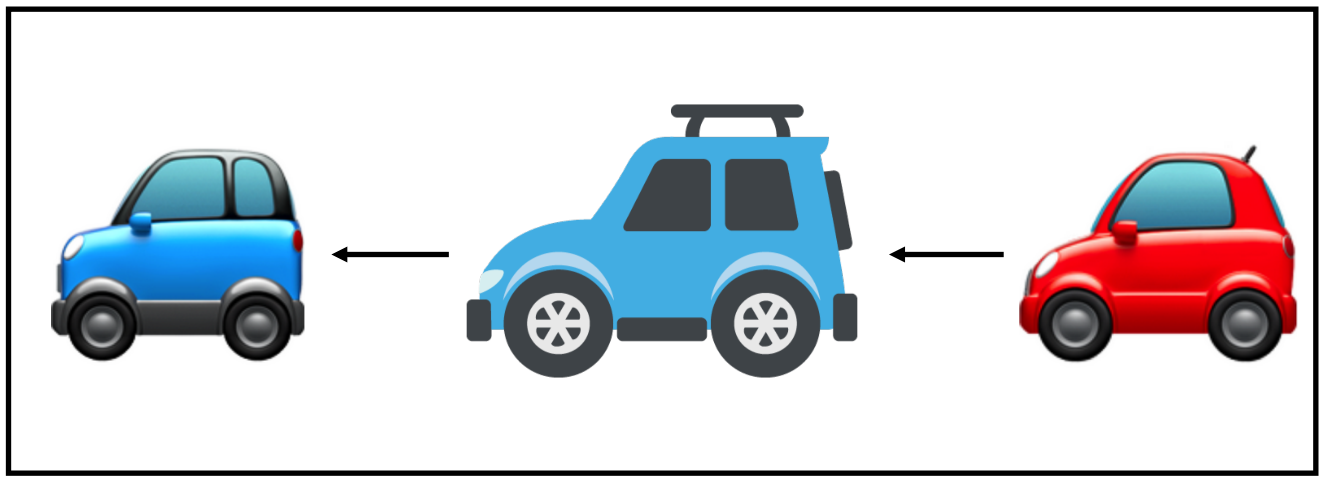
- Criminal specialization
- Some types of crime require cooperation
- Cooperating with a criminal intent requires secrecy and trust

Motifs

M Tumminello, C Edling, F Liljeros, RN Mantegna, J Sarnecki (2013) The Phenomenology of Specialization of Criminal Suspects. PLoS ONE 8(5): e64703. doi:10.1371/journal.pone.0064703

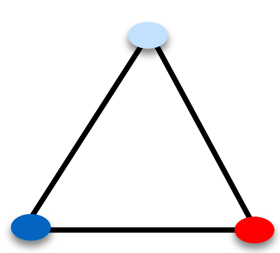
Motifs and anti-fraud

Not suspicious

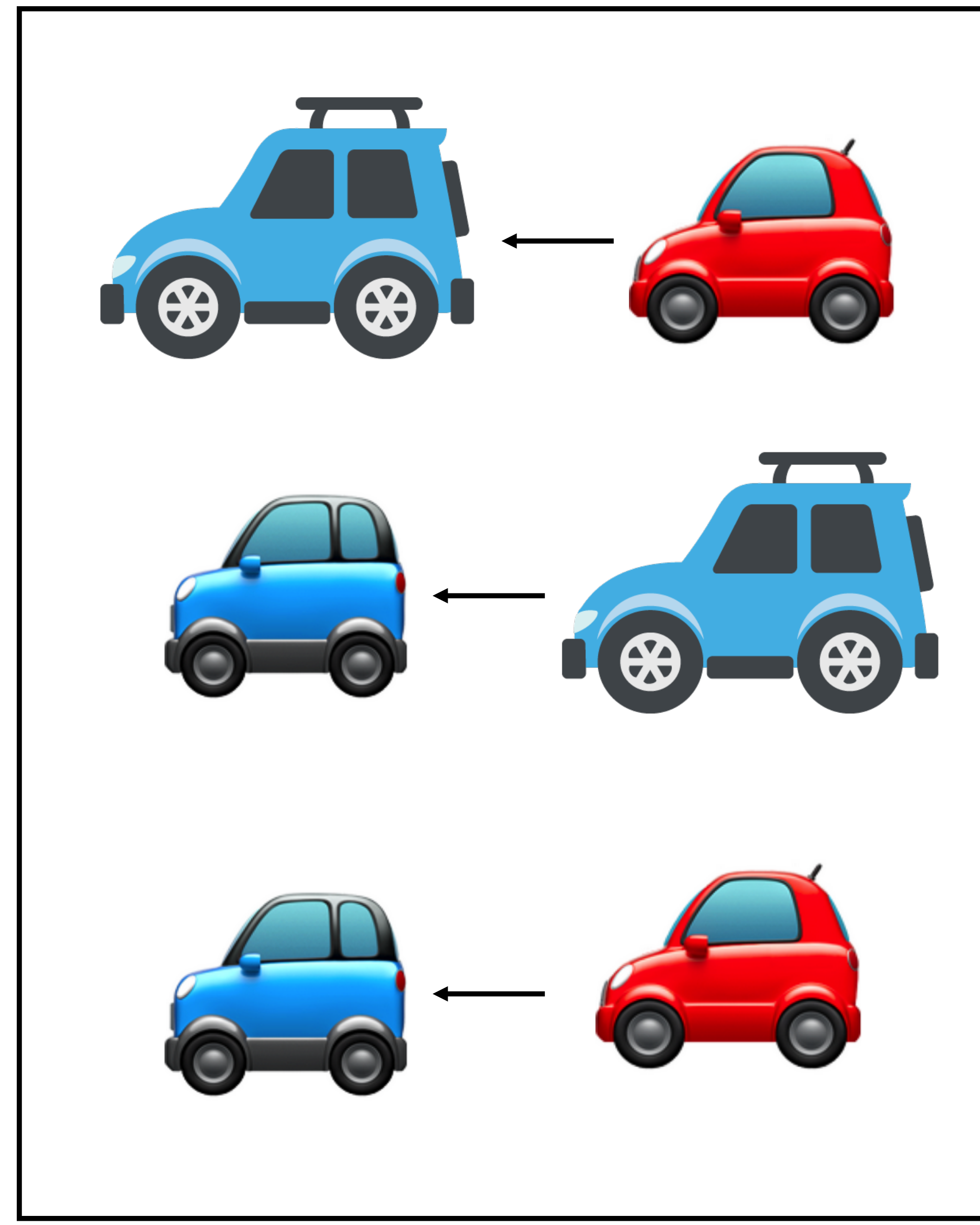


A single event involving three cars

Same projection

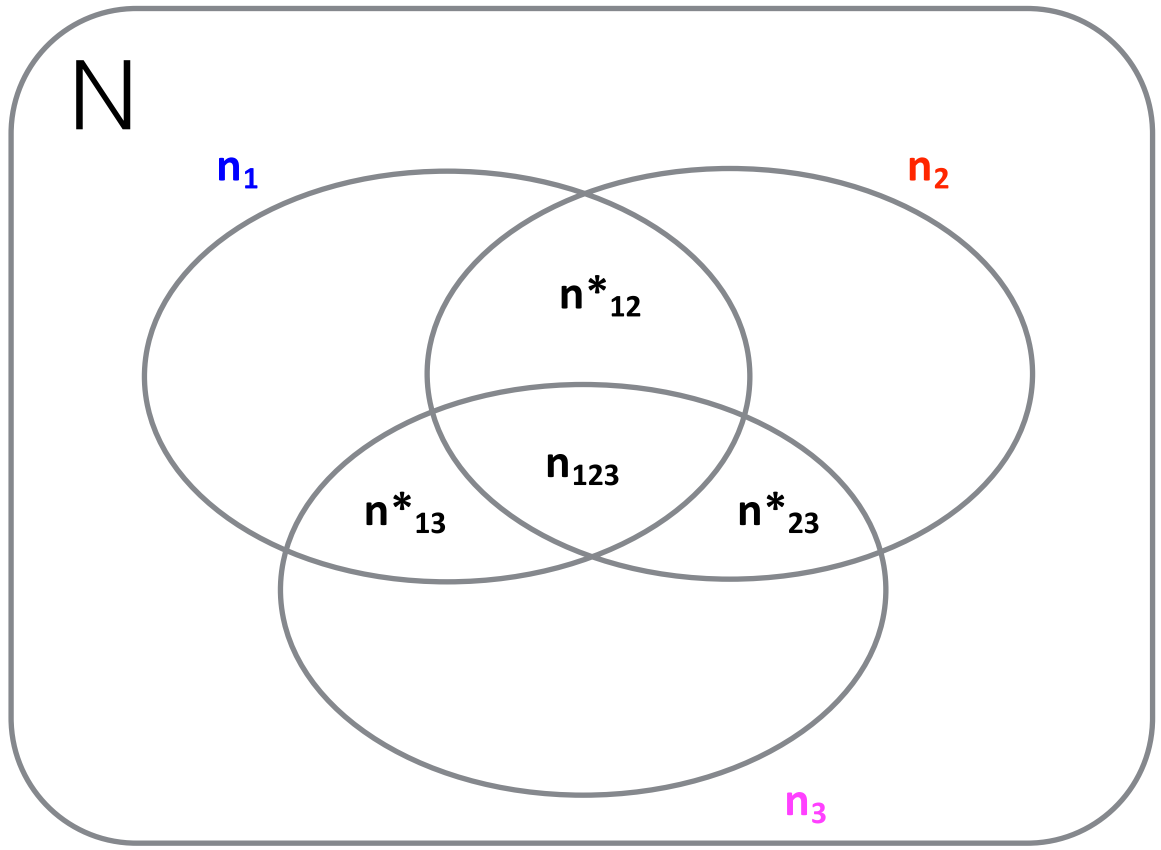


Suspicious



Three events involving three cars

Three-node motifs: statistically validated triangles



Proposition: if random co-occurrence of three subjects, 1,2, and 3, involved in n_1, n_2, and n_3 events, respectively, is assumed in a dataset including N events then

$$p(n_{12}^*, n_{13}^*, n_{23}^* | n_1, n_2, n_3, N) = \sum_{n_{12}} \frac{\binom{n_1}{n_{12}}\binom{N-n_1}{n_2-n_{12}}\binom{n_{12}}{n_{12}-n_{12}^*}\binom{n_1-n_{12}}{n_{13}^*}\binom{n_2-n_{12}}{n_{23}^*}\binom{N-n_1-n_2+n_{12}}{n_3-n_{13}^*-n_{23}^*-n_{12}-n_{12}^*}}{\binom{N}{n_2}\binom{N}{n_3}}$$

$$\text{p-value} = p(n_{12}^* + n_{13}^* + n_{23}^* \geq n_{12}^{*,0} + n_{13}^{*,0} + n_{23}^{*,0})$$

Three-node motifs and antifraud

Network of directly involved subjects (no professionals)

- Number of triangles: 162,409
- Number of statistically validated triangles:60,523

Randomly rewired network of directly involved subjects

- Average number of triangles: 18,535
- Average Number of statistically validated triangles: 0.08

Final Remarks

1. The network of subjects and vehicles carry different information.

2. Introduced network indicators and IVASS subject indicators carry complementary information, and, therefore, can fruitfully be integrated.

3. The test on “claims closed following investigation” and the analysis of a few case studies indicate the effectiveness of the overall approach.

4. Introduced network indicators will be operative by Jan 2018.

5. Next steps: (a) integrating three-node motifs in the SVN (exp. Jun 2017); (b) developing an integrated indicator (exp. end 2018);

Thanks!

Michele Tumminello

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Turning the map into a globe

Logic in forecasting and decision making

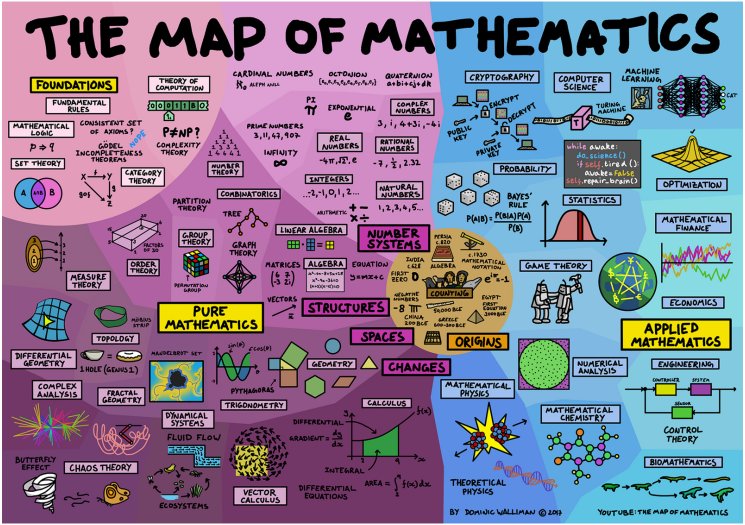
Hykel Hosni

Associazione Italiana di Logica e Applicazioni

UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI FILOSOFIA
http://www.filosofia.unimi.it/~hosni/

Giornata FIMA - CNR Roma
27/10/2017

A comprehensible misunderstanding



but a misunderstanding nonetheless!

A very long story, short

BEGRIFFSSCHRIFT,

EINE DER ARITHMETISCHEN NACHGEBILDETE

FORMELSPRACHE

DES REINEN DENKENS.

VON

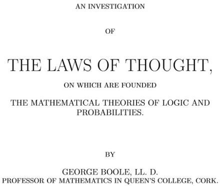
Dr. GOTTLOB FREGE,

PRIVATDOCENTEN DER MATHEMATIK AN DER UNIVERSITÄT JENA.

HALLE a/S.

VERLAG VON LOUIS NEBERT.

1879.



AN INVESTIGATION

OF

THE LAWS OF THOUGHT,

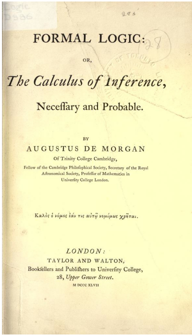
ON WHICH ARE FOUNDED

THE MATHEMATICAL THEORIES OF LOGIC AND PROBABILITIES.

BY

GEORGE BOOLE, LL. D.

PROFESSOR OF MATHEMATICS IN QUEEN'S COLLEGE, CORK.



FORMAL LOGIC:

OR,

The Calculus of Inference,

Neceffary and Probable.

BY

AUGUSTUS DE MORGAN

Of Trinity College Cambridge,

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Καλὸς ὁ νόμος ἐάν τις αὐτῷ νομίμως χρῆται.

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M DCCC XLVII

A very long story, short


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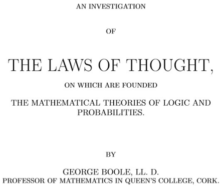
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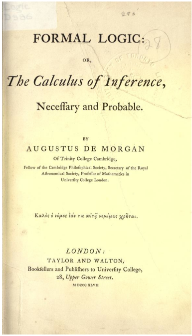
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1980s - today

AI thrives on combining Fregean rigour and Boolean ambition

$P : \mathcal{SL} \to [0, 1]$ is a *probability function* on $\mathcal{L}$ if it satisfies

Normalisation

$$\models \theta \Rightarrow P(\theta) = 1$$

Additivity

$$\models \neg(\theta \wedge \phi) \Rightarrow P(\theta \vee \phi) = P(\theta) + P(\phi)$$

$P : \mathcal{SL} \to [0,1]$ is a *probability function* on $\mathcal{L}$ if it satisfies

Normalisation

$$\models \theta \Rightarrow P(\theta) = 1$$

Additivity

$$\models \neg(\theta \wedge \phi) \Rightarrow P(\theta \vee \phi) = P(\theta) + P(\phi)$$

... **and what is to be found there**

Diagnosis

$\models$ is liable for unwelcome features

- "uncertainty $\neq$ ignorance"
- SAT is NP-complete

Treatment

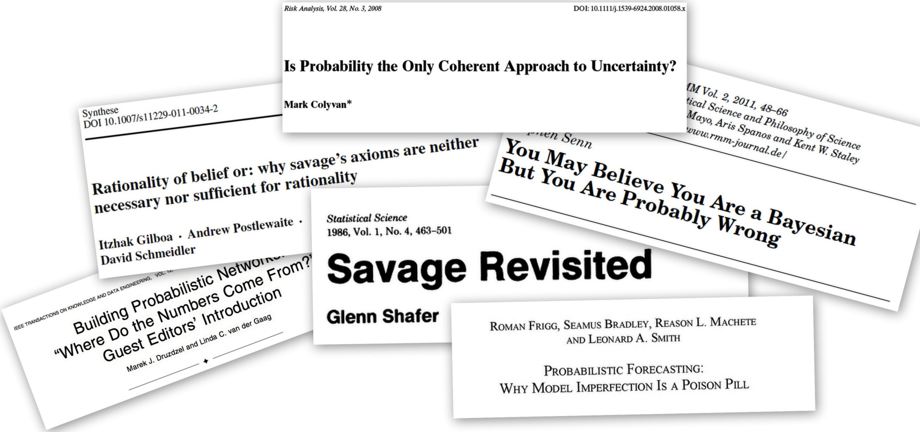
Use a better logic!

Overview

1. Why is this relevant?
2. Logic in action
3. Current initiatives

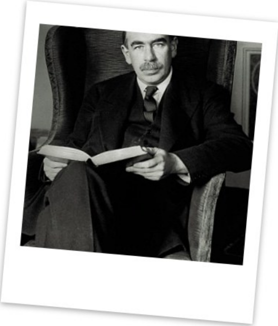
Probability and its critics

A recent selection



The argument from information

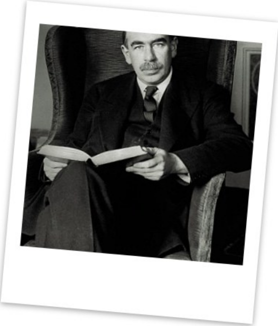
The sense in which I am using the term ['uncertain' knowledge] is that in which the prospect of a European war is uncertain [...] About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know.



J. M. Keynes, *The General Theory of Employment* Q.J.E. 51 (1937): 209-23.

The argument from information

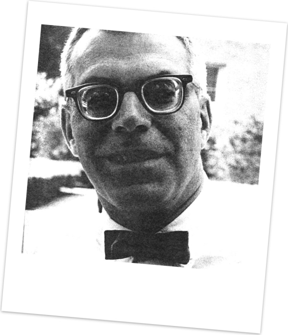
The sense in which I am using the term ['uncertain' knowledge] is that in which the prospect of a European war is uncertain [. . .] About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know. ***Nevertheless****, the necessity for action and for decision compels us as practical men to do our best to overlook this awkward fact and to behave exactly as we should if we had behind us a good Benthamite calculation of a series of prospective advantages and disadvantages, each multiplied by its appropriate probability, waiting to be summed.*



J. M. Keynes, *The General Theory of Employment* Q.J.E. 51 (1937): 209-23.

The argument from tractability

A person required to risk money on a remote digit of π would have to compute that digit in order to comply fully with the theory though this would really be wasteful if the cost of computation were more than the prize involved. ***For the postulates of the theory imply that you should behave in accordance with the logical implications of all that you know****. Is it possible to improve the theory in this respect, making allowance within it for the cost of thinking, or would that entail paradox [...] ? If the remedy is not in changing the theory but rather in the way in which we attempt to use it, clarification is still to be desired.*



L. J. Savage (1967), "Difficulties in the theory of personal probabilities"

Logic in action

Good forecasts should be (at least)

- Coherent
- Accurate
- Useful

Suppose

θ : "Italy's GDP for 2017 will increase by 2.5%"

ϕ : "Average pay for fresh gradates in 2020 will be > 1000 E"

To evaluate the *coherence* and *accuracy* of forecasts such as $P(\theta \wedge \phi)$, $P(\neg\phi)$, etc. we need to be able to resolve the relevant uncertainty (i.e. wait until we can assign a truth-value to the relevant sentences/events) according to well defined logical rules.

The classical case

Let $\theta_1, \ldots, \theta_n$ be events in a logical language $\mathcal{L}$ and $\mathbb{V}$ the set of CLASSICAL logical valuations $v : \mathcal{L} \to \{0, 1\}$, i.e. which OBEY THE STANDARD BOOLEAN TABLES. The assessment

$$\Phi : \theta_1 \mapsto \alpha_1, \ldots, \theta_n \mapsto \alpha_n,$$

where $\alpha_i \in [0, 1]$, $i = 1, \ldots, n$. is *coherent* if real numbers $\sigma_1, \ldots, \sigma_n$ cannot be found such that for every valuation v

$$\sum_{i=1}^{n} \sigma_i(\alpha_i - v(\theta_i)) < 0.$$

Theorem (De Finetti 1931)

An assessment Φ is **coherent** iff there is a probability distribution P which extends it, that is, $P(\theta_i) = \alpha_i$ for $i = 1, \ldots, n$.

When 2 is not enough

home › world › europe | US americas asia australia africa middle east cities development

Catalonia

Spanish PM asks Catalonia: have you declared independence or not?

Mariano Rajoy gives Catalan president until Monday to clarify as he considers invoking article 155 to suspend region's autonomy

1,388

Sam Jones in Barcelona

@swajones

Wednesday 11 October 2017 17.43 BST

The Spanish prime minister, Mariano Rajoy, has refused to rule out imposing direct rule over Catalonia. Photograph: Angel Diaz/EPA

- The many banks and firms which moved out of Barcelona after the referendum made presumably coherent forecasts nonetheless!

More generally

Partially-resolving uncertainty is typical when considering *informational events*.

$$v(\theta) = \begin{cases} 1 \text{ if I am informed that } \theta \\ 0 \text{ if I am informed that } \neg\theta \\ \perp \text{ if I am not informed about } \theta \end{cases}$$

Recently a family of logics based on this semantics have been developed, which *as a bonus* provide tractable approximations of $\models$

▸ more

D' Agostino, M., Finger, M., & Gabbay, D. (2013). Semantics and proof-theory of depth bounded Boolean logics. *Theoretical Computer Science*, 480, 43-68.

IPCC 2007 Summary for Policymakers

"By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (high confidence)."

Multiple layers of uncertainty:

- "arid" and "semi-arid" are clearly *vague* concepts
- the expected increase is given in the form of an interval
- the uncertainty of the overall statement is quantified with "high confidence"

$\models$ is clearly inadequate to model the uncertainty resolution mechanism in cases like this

Łukasiewicz logic (and MV-algebras)

An illustration of the setup

- Truth values range over $[0, 1]$
- For each connective there exists a fixed function which determines the truth-value of complex sentences:

$$
\begin{aligned}
F_{\neg}(x) &= 1 - x \\
F_{\wedge}(x, y) &= \max\{0, x + y - 1\} \\
F_{\vee}(x, y) &= \min\{1, x + y\} \\
F_{\rightarrow}(x, y) &= \min\{1, 1 - x + y\}
\end{aligned}
$$

- normalised and additive measures (called *states*) are defined on the resulting logic

D. Mundici, *Advanced Łukasiewicz calculus and MV-algebras*, Springer 2011.

Current initiatives

Lorentz center

Models of Bounded Reasoning in Individuals and Groups, Lorentz Center, Leiden. 2-6 July 2018, co-organised with

- D. Grossi, Computer Science, Liverpool
- S. Modgil, Computer Science, KCL

LAKE COMO SCHOOL OF ADVANCED STUDIES

Summer School on Logic, Uncertainty and Games, Lake Como School of Advanced Studies, 9-13 July 2018, co-organised with

- P. Battigalli, Decision Sciences, Bocconi
- M. Marinacci, Decision Sciences, Bocconi

Teaching

Programs > Undergraduate School > Prospective Students > Economic and Social Sciences > Program Structure

- Program Structure
  - » Educational Objectives
  - » Study Plan
  - » Intended Learning Outcomes
  - » Career Opportunities

Program structure - Economic and Social Sciences

FIRST YEAR

Main topics

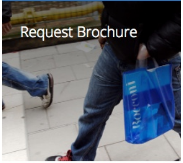
- **Economics (micro and macro)**
- **Math (theoretical and applied)**
- **Logic and Methods for Social Sciences**
- **Management**

First foreign language
Computer science

During the first year, you will be given training in several basic subjects in order to understand how companies and organizations work (**Management**), as well as the economic system in which they operate. **Economics**, in fact, describes the functioning of economic systems both at an overall level (macroeconomics) and at the level of the individual behavior of firms and consumers (microeconomics). Through **Math** and **Statistics**, both theoretical and applied, you will be provided with a wide set of quantitative tools to understand and apply an array of economic models. Finally, the course in **Logic and Methodology of Social Sciences** gives you the fundamentals of logic and critical thinking to understand how the mind should work in order to detect fallacious patterns of reasoning (when does B follow from A?), assess and (de)construct arguments, think consistently and analytically.

Links

- **Foreign Languages**
- **IT Skills**



References

- Video Podcasts on `https://youtu.be/fKyETgxdbM8`
- Volume 2 out in March 2018

Logic in forecasting and decision-making

- M. D'Agostino, T. Flaminio, and H. Hosni. "Rational beliefs real agents can have – A logical point of view". In: *Journal of Machine Learning Research: Workshops and Conference and Proceedings* 58 (2017), pp. 1–13.
- T. Flaminio, H. Hosni, and S. Lapenta. "Convex MV-Algebras: Many-Valued Logics Meet Decision Theory". In: *Studia Logica* Online First (2017).
- T. Flaminio, H. Hosni, and F. Montagna. "Strict coherence on many valued algebras". In: *Journal of Symbolic Logic* (in print) (2017).

Informational semantics

$\wedge$	1	0	$\bot$
1	1	0	$\bot$
0	0	0	0
$\bot$	$\bot$	0	$\bot, 0$

$\vee$	1	0	$\bot$
1	1	1	1
0	1	0	$\bot$
$\bot$	1	$\bot$	$\bot, 1$

$\neg$	
1	0
0	1
$\bot$	$\bot$

The hierarchy of tractable approximations of $\models$

- $\models_0$ is defined by taking the closure under the informational tables
- $\models_k$, $i \in \mathbb{N}$ is built in discrete steps by *assuming* that a sentence which was left undecided at level $k-1$ is now taking either 0 or 1.
- Each k yields a polynomial decision procedure
- $\models_\infty$ coincides with $\models$

back