Complex Automata Simulation Technique

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Coast

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Complex Systems

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www.complex-automata.org

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Coast Objectives

The Objectives of COAST are

1. Develop a multi-scale, multi-science framework coined *Complex Automata* for modelling and simulation of complex systems based on hierarchical aggregation of coupled Cellular Automata and agent based models;
2. Develop a mathematical framework for Complex Automata, allowing transformation into a generic modelling and simulation framework;
3. Identify basic ways in which information can be shared between sub-models within a Complex Automaton;
4. Develop a modelling and simulation software framework;
5. Validate the Complex Automaton framework by applying it to a very challenging and highly relevant biomedical application, related to treatment of coronary artery diseases;
6. Model the process of tissue re-growth after stent placement as a Complex Automaton, implement it in the Complex Automata environment, and run simulations to optimise design of drug-eluting stents.

Workpackages

- WP1 Management
- WP2 Complex Automata
  - To realise a mathematical foundation of the concept of Complex Automata.
  - To identify the main mechanisms of coupling automata spanning length and time scale, leading to a formal modelling language for Complex Automata
- WP3 Model Embedding
  - To build the generic software environment for Complex Automata, based on an existing agent-based computational environment allowing a high-level and straightforward implementation of the hierarchical coupling schemes developed in WP 2 including the overall system's control structure.
  - To adapt the generic coupling framework to the specific requirements of the prototype application.
- WP4 Validation
  - To develop a series of metrics to facilitate comparison between the output of the computational model and *in vivo* data.
  - To tune parameters in biological rule-set using subset of experimental data
  - To validate the model by comparison with *in vivo* data.
  - To demonstrate the portability of the generic framework to other applications.
- WP5 Dissemination

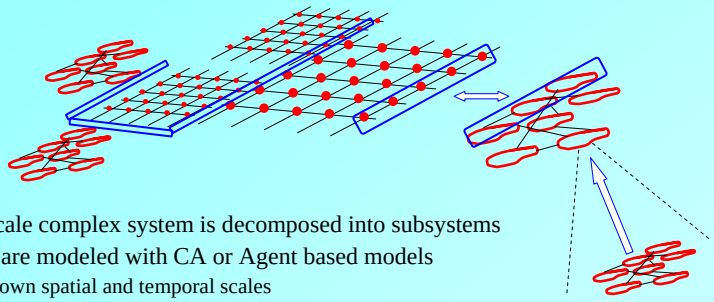
Our Approach

"**Less** is **More**"

- Focus on Cellular Automata and Agent Based models
- Most promising generic approach for modeling complex systems.

- Allows us to develop generic multi-scale modeling approach.
- Develop an integrated multi-scale modeling and simulation environment.
- Facilitate system engineering and design of complex systems.

Complex Automata



- Full multi-scale complex system is decomposed into subsystems
- Subsystems are modeled with CA or Agent based models
  - On their own spatial and temporal scales
  - With private or shared clocks
  - Synchronous or asynchronous updates
- Coupling by sharing information
  - Spatially and or temporaly resolved signal, through e.g. the boundaries
  - Lumped parameters, with weak temporal coupling
  - others

Key Challenges

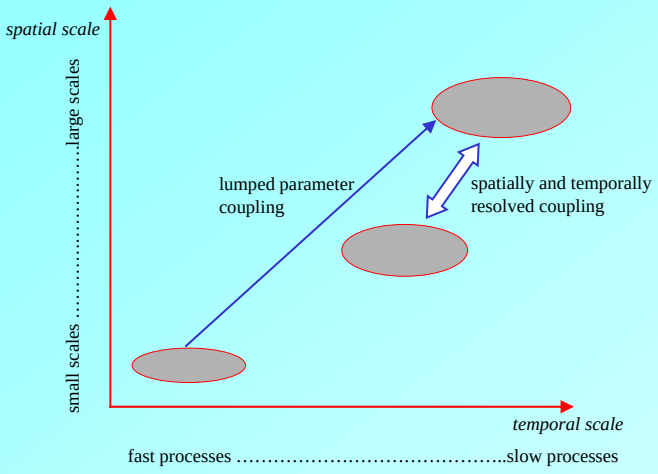
- How to identify components
- How to select the appropriate temporal and spatial scales
- How to couple them (through lumped parameters or resolved signals)

Selection of scales and scale separation

- Based on previous scientific knowledge, or could be inferred from detailed studies of sub-systems
- Builds up as an emergent property in the system
- Sometimes scale separation is not possible

  (and the Coast approach will not be beneficial)

Scale Map



1. Draw a scale map
2. Place subsystems on the map
3. Draw edges to show coupling between subsystems

Model Embedding

- Identify generic coupling mechanisms
  - E.g. shared boundaries, or extracting parameters from one subsystem that are used in update rules of another subsystem
- Specification of dynamics
  - Subsystems themselves are synchronously updated with constant time steps
  - Coupling may involve several paradigms
    - Time driven
      - Fully synchronous
      - Loosely synchronous
      - Asynchronous
    - Event driven
    - Mixed time / event driven
- Mathematical formulation for Complex Automata

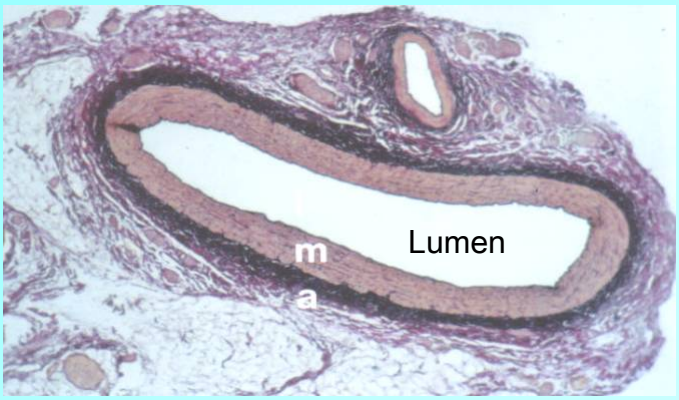
Complex Automata software

- We plan to deliver a generic software environment for simulation of Complex Automata
- Based on existing software
  - For distributed simulation (e.g. HLA)
  - For CA's (e.g. CAMEL) and Agent Based models (e.g. Jade, X-machines)
- Supplemented with Complex Automata libraries
  - For model embedding
    - Implementing the generic coupling mechanisms
  - For handling the dynamics
    - (a)synchronous time driven and/or event driven

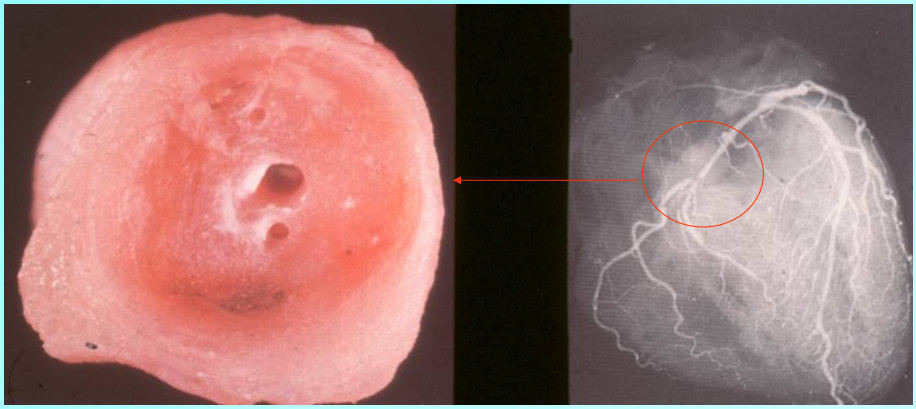
Our Case Study, in-stent restenosis

- Related to treatment of coronary artery disease
  - arteries supplying the heart muscle with blood become occluded (stenosed)
  - one treatment involves expansion of the stenosis and support of the vessel wall by means of a metal frame (stent)
  - for a significant number of individuals the effect of this treatment is short-lived as tissue grows around the frame and into the lumen of the vessel (in stent restenosis)
- A highly relevant biomedical problem.
- With a large collection of subsystems, operating on a wide range of time- and length scales.

Normal artery



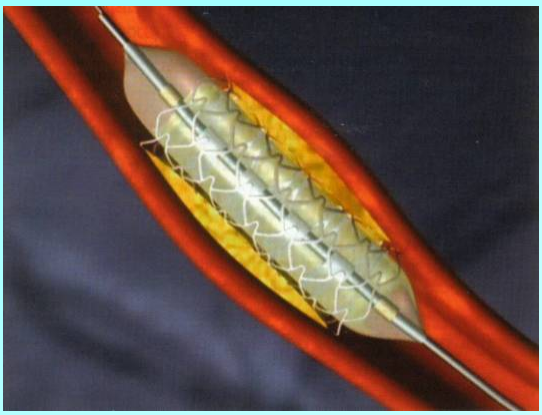
Coronary artery disease



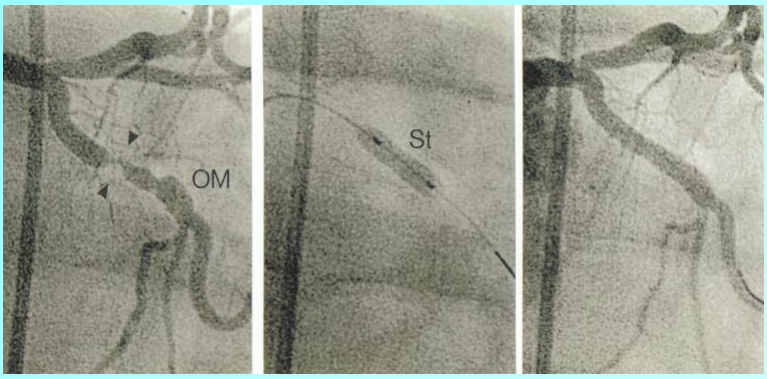
Gross appearance

Angiogram

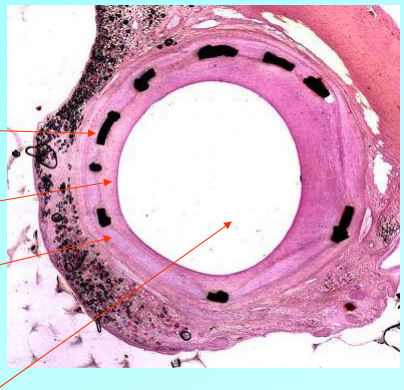
Stent implantation



Stent implantation



A stented artery



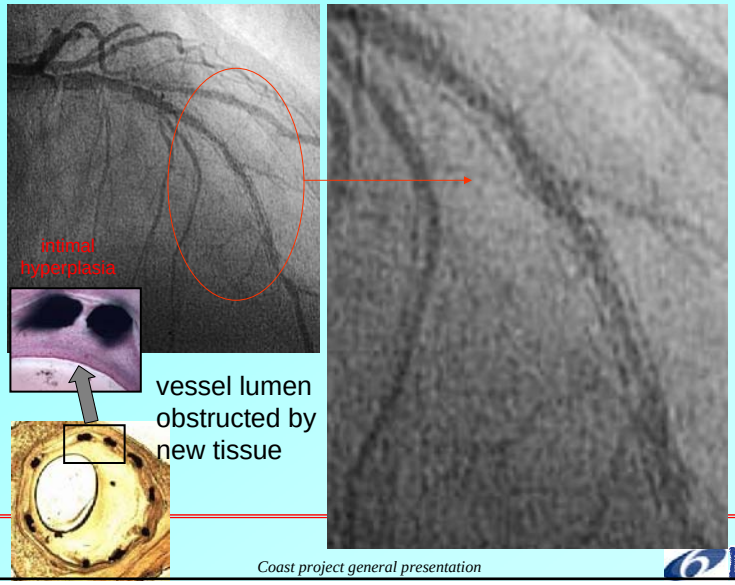
Stent struts

Tissue covering stent

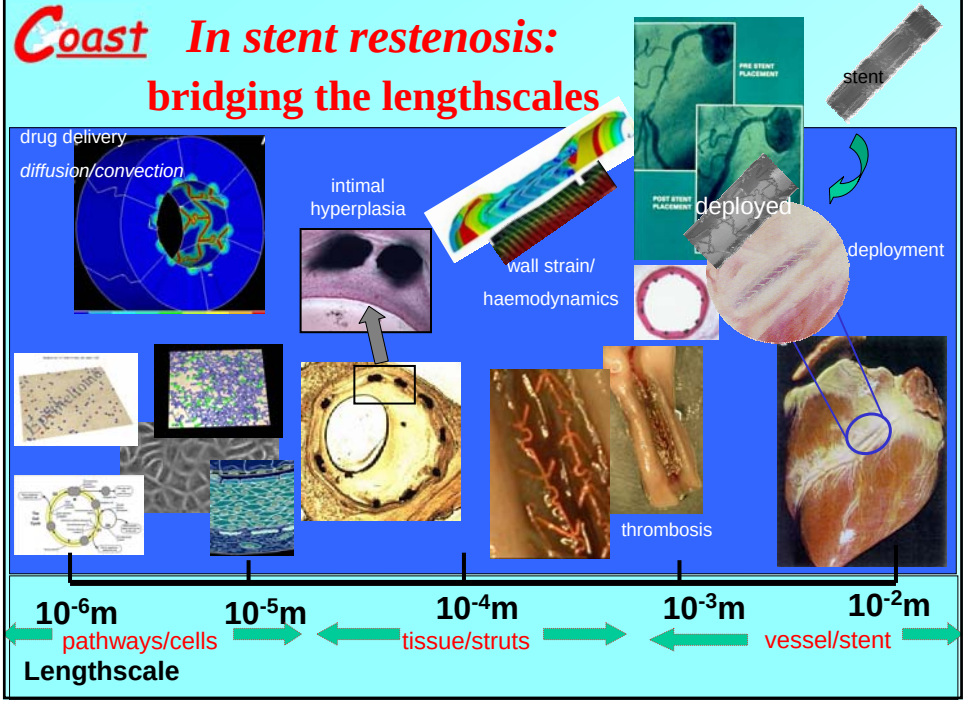
Artery wall

Smooth lumen opened by stent carrying blood

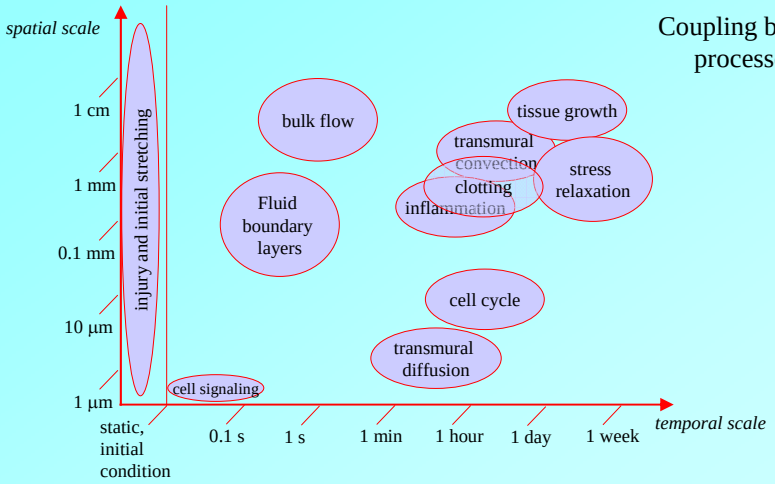
In-stent restenosis



In stent restenosis: bridging the lengthscales

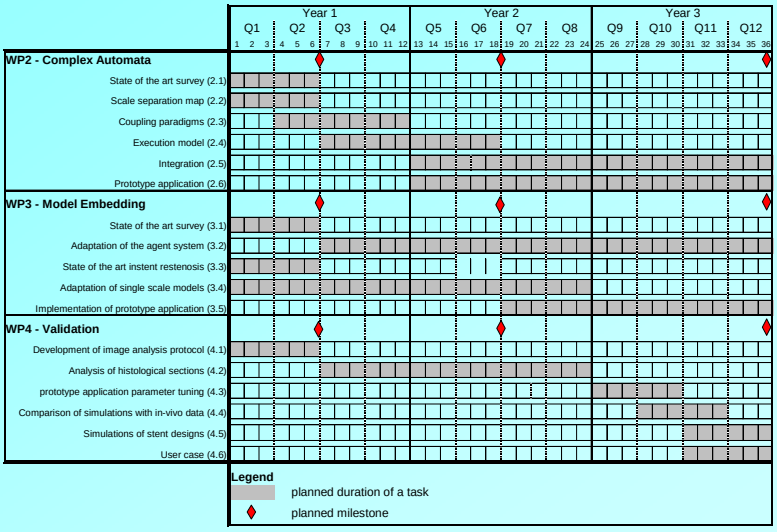


Scale Map for in-stent restenosis, v1

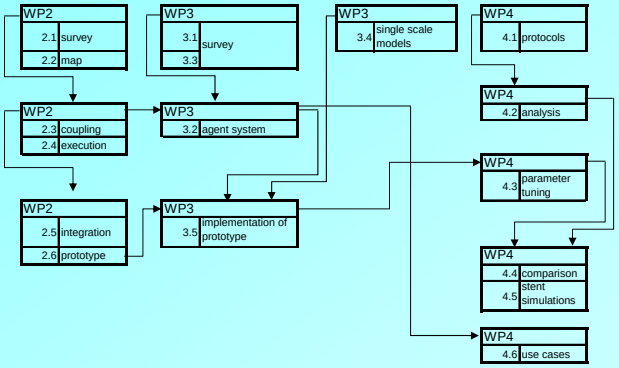


Coupling between sub-processes is missing.

Planning



Dependencies



Deliverables

Deliverable No	Deliverable title	WP No	Lead participant	estimated person months	Delivery date	Nature	Dissemination level
D1.1	Quality Assurance plan (including risk analysis)	1	UvA		3	R	CO
D1.2.1 – D1.2.6	Bi-annual Project progress reports from coordinator to Project Collaboration Board	1	UvA		6, 12, 18, 24, 30, 36	R	CO
D1.3	First periodic reporting to the EC (Activity report, Management report, report on distribution of EC contribution)	1	UvA		13	R	CO
D1.4.1 – D1.4.3	Audit certificates per contractor per reporting period	1	UvA		13, 25, 36	R	CO
D1.5	Second periodic reporting to the EC (Activity report, Management report, report on distribution of EC contribution)	1	UvA		25	R	CO
D1.6	Final periodic reporting to the EC (Activity report, Management report, report on distribution of EC contribution)	1	UvA		36	R	CO
D2.1	State of the art survey on CA and agent based models for multiscale modelling, and a report of the scale separation map and coupling paradigms	2	UNIGE		12	R	PU
D2.2	Formal description of Complex Automata, including report on execution models, and draft version of complex automaton model for prototype application	2	UNIGE		24	R	PU
D2.3	Complex Automata theory and modelling language, and final version of complex automaton model for prototype application	2	UNIGE		36	R	PU
D3.1	State of the art survey on agent platforms and mechanisms of in-stent restenosis together with design specifications for the Complex Automata simulation software and the single scale models	3	TUB		12	R	PU
D3.2	First release of the software (packages) for Complex Automata simulation, adapted single scale models and in-stent restenosis	3	TUB		24	R, P	PU
D3.3	Report and final release of the software (packages) for Complex Automata simulation, adapted single scale models and instant restenosis	3	TUB		30	R, P	PU
D4.1	Formal statement of biological ruleset, preliminary survey of application dataset including analysis protocols	4	USFD		12	R	PU
D4.2	Formal report on application dataset including complementary histological analysis	4	USFD		24	R	PU
D4.3	Report on exercise of Coast Software Suite in the target application of in-stent restenosis and quantitative evaluation of performance	4	USFD		36	R	PU
D5.2.1 – D5.2.3	Website first, intermediate and final version including an archive for dissemination results	5	UvA		1, 12, 30	P, O, O	PU
D5.3.1 – D5.3.3	Presentation with project goals and state of the art, publications to the general public and other stakeholders	5	UvA		12, 24, 36	P, O, O	PU
D5.4	Plan of using and disseminating knowledge	5	UvA		18	R	RE

Societal Impact

- Coronary artery disease is the major cause of death in the Western World; in 2003. The associated costs are estimated to be ~ €45 billion.
- Worldwide/year ~3million cases of coronary artery disease are treated by stenting (increasing 10-15%/year as the population ages) leading to a EU Market for these devices of >$1.4 billion/year.
- Following stenting, 5-10% of patients develop restenosis; before drug-eluting stents (DES) were introduced, this figure was 10-20% and since drug-eluting stents, 4-8% develop restenosis.
- Modelling can aid understanding of the underlying factors and lead to the development of improved DES technology with reduced cost and development times, and improved outcomes.

List of Milestones

- Month 6
  - State of the art surveys
  - Decision on technology
  - Image analysis protocol for validation case
- Month 18
  - draft of Complex Automata theory
  - first outline of Complex Automata model of prototype application
  - Version 1 of Coast simulation software available
- Month 24
  - In vivo data for validation available
- Month 36
  - Final version of Complex Automata theory available
  - Final version of Coast simulation software available
  - Validated Complex Automata model of prototype application, including its implementation
  - Examples of stent design available

Contact Information

For more information on COAST, please contact

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