BIOMICS

An Interdisciplinary Overview of Interaction Computing

Lecture 1

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SEVENTH FRAMEWORK PROGRAMME

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BIOMICS:
Biological and Mathematical Basis of Interaction Computing

BIOMICS aims to achieve biological (ontogenetic, not philogenetic) self-organization in software or, more precisely, in computational systems

BIOMICS postulates that to achieve the self-organization of computational systems we need to develop a new model of computation that transcends the Turing Machine and that is based on interactions

Thus, in these two lectures I will discuss:

- biological self-organization
  - architectural aspects
  - dynamical aspects

- computational systems that may be able to emulate it
  - Turing Machines, Pi Calculus, Abstract State Machines, Interaction Machine

- some aspects of the (mathematical) bridges between them
  - continuous vs. discrete mathematics
  - symmetries, algebras, coalgebras, category theory

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Overview

- Biocomputation according to BIOMICS
- Some global architectural considerations
- Abstraction/representation theory
- BIOMICS computational framework
- Constructive models, ontology and epistemology

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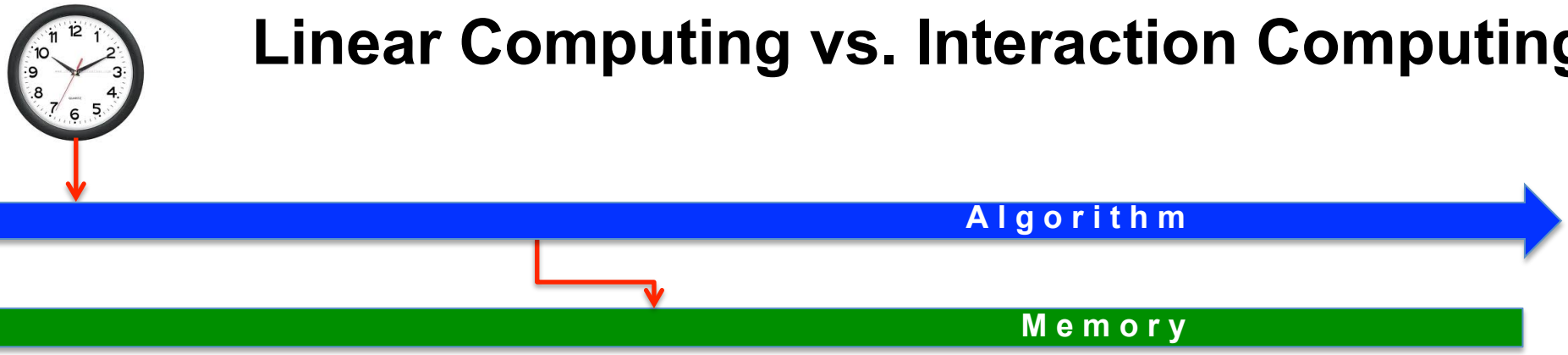
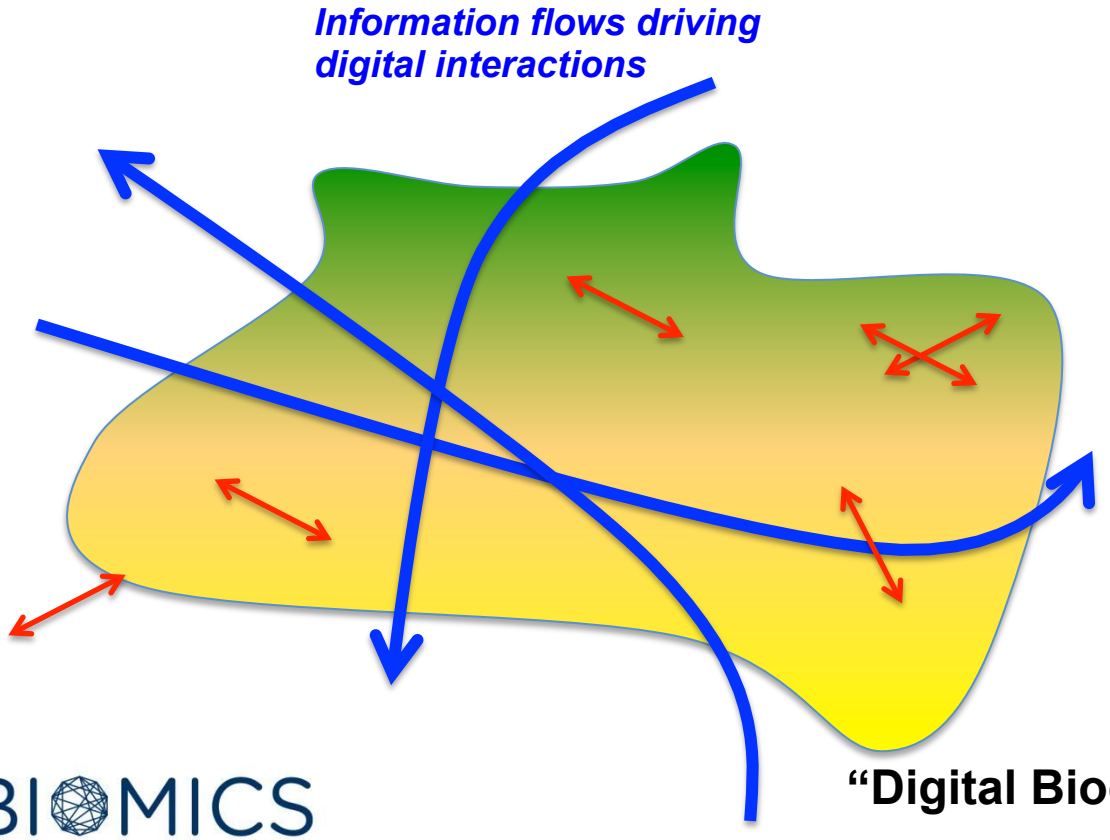
Linear Computing vs. Interaction Computing





- No clock: events driven by external triggers
- Many parallel and interdependent algorithms
- Interaction model is recursive: nested & hierarchical
- Memory is distributed

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"Digital Biochemistry"

Open Systems, and Self-Organization as the Fall Towards Equilibrium

- The ‘self’ in self-organization indicates a ***spontaneous*** time evolution towards greater order.

- In physical systems ***spontaneous*** time evolution can only happen if a system is approaching or “falling towards” (thermodynamic) equilibrium.

- A closed system approaching equilibrium (minimum energy and/or maximum entropy) will eventually stop.

- Hence, in biology equilibrium is death, and must be avoided as long as possible – however, the ***fall*** towards equilibrium remains essential to self-organization.

- Therefore, biological organisms must be ***open*** to a flow of energy and information (i.e. food) that keeps them away from equilibrium ***even while they continue falling towards it!***

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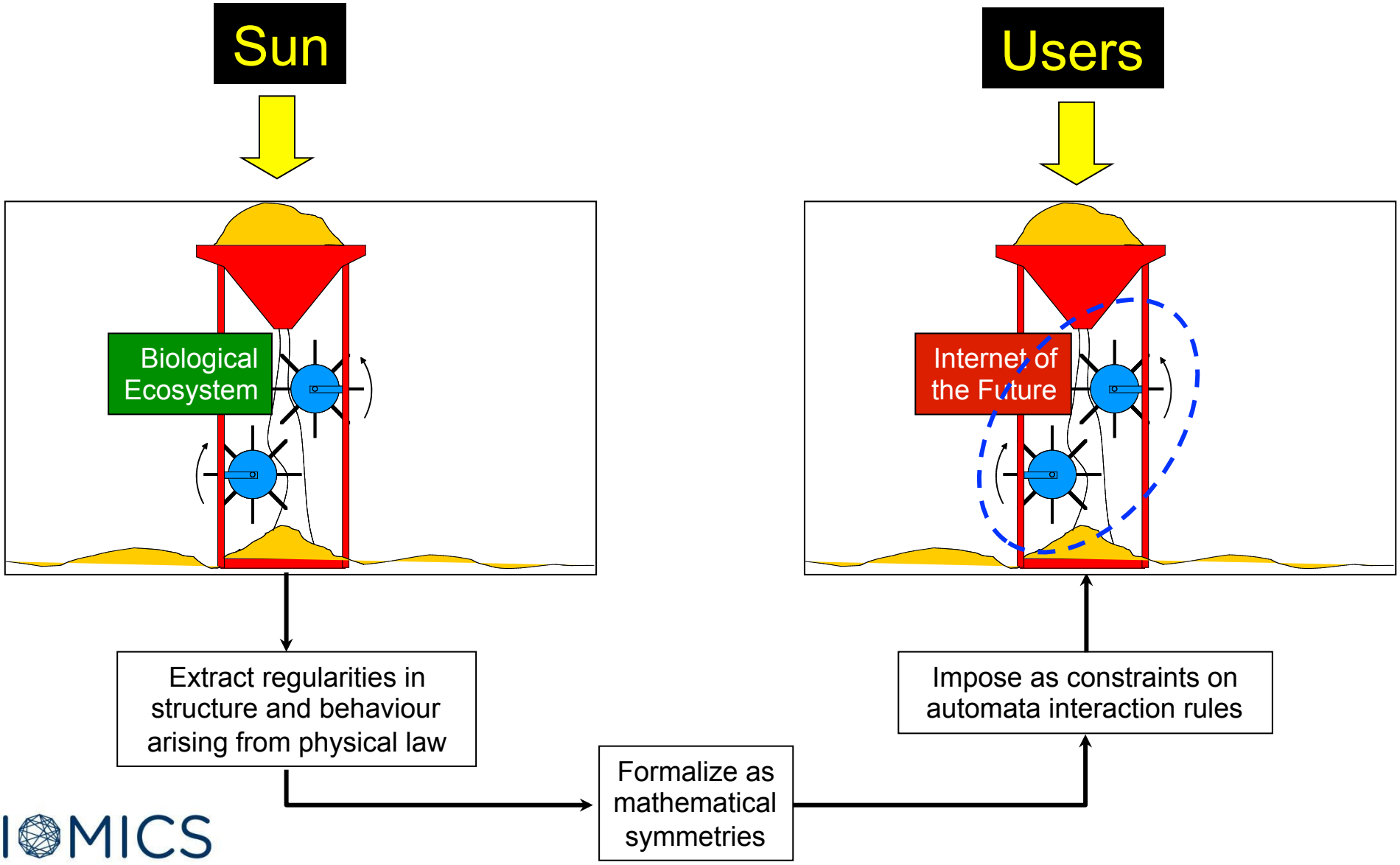
Open Systems, Formalization and (Non-Linear) Interaction: A Simplistic View



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Why Simplistic?

- In early 2012 we postulated that self-organization could be understood and modelled based on non-linear interactions and algebraic structure (e.g. symmetries or invariant quantities) of the systems in question.

- Although symmetries and algebraic structure still seem ***necessary***, we are beginning to suspect they are not ***sufficient***.

- So we are starting to think about '***constructive***' models as well.

*These considerations apply to **both** biology and computation*

- Furthermore, the temperature of computational systems is zero, in the sense that if they are not "pushed" nothing happens. So thermodynamic analogies like the fall towards equilibrium and random mixing have to be made with care and may apply only in some limit or in a degenerate sense.

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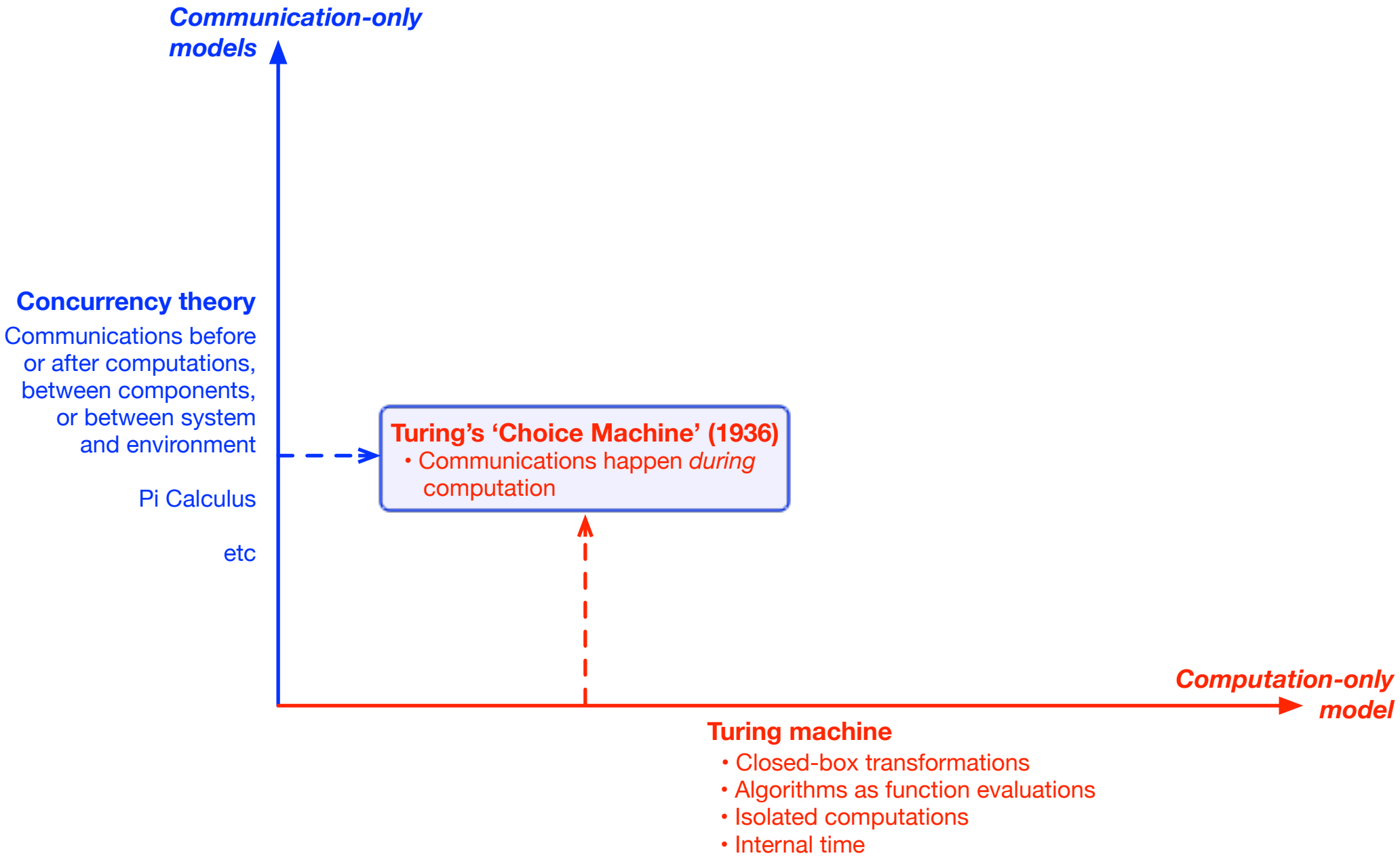
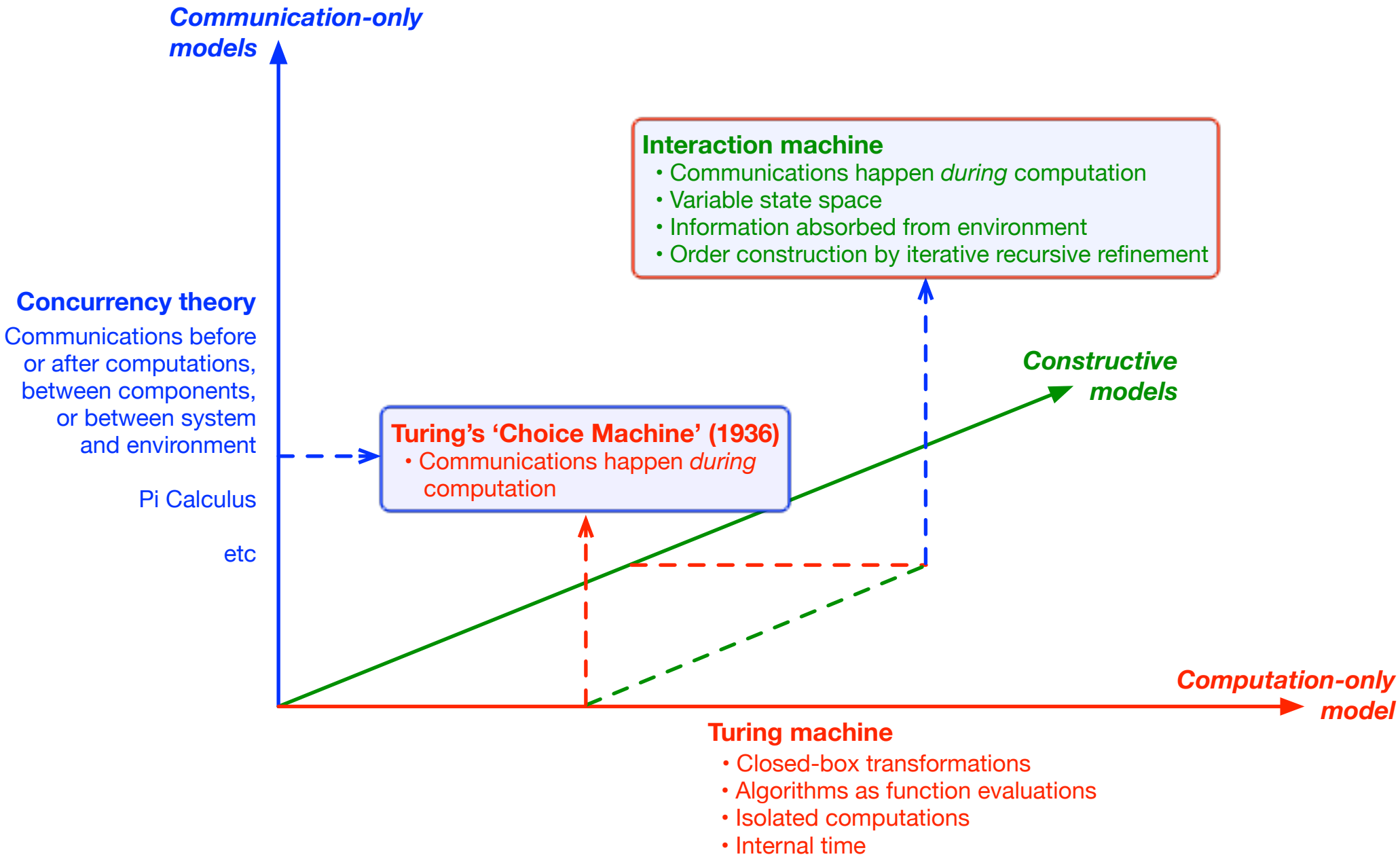
Models of Computation

(Theory catching up with practice…)



Models of Computation

(Theory catching up with practice…)



‘Constructive’ Computational and Mathematical Models in the Context of Abstraction/Representation Theory

‘Physical computing is the use of a physical system to predict the outcome of an abstract evolution’[1]

- Normally, the computational model of an abstract evolution is a finite-state machine with a fixed number of states.

- However, if we think of ontogenetic processes like morphogenesis or even just ‘simple’ metabolism, clearly a fixed number of states is not sufficient.

- Furthermore, modern web-based computational architectures cannot be modelled with a single Turing Machine.

- BIOMICS is trying to develop the computational model – and the mathematical model above that – that corresponds to ‘constructive’ and interacting biological processes (and that may better support distributed architectures).

- The problem is that we don’t have a precedent for either kind of model, we have to invent a new computational model and some new mathematics above that.

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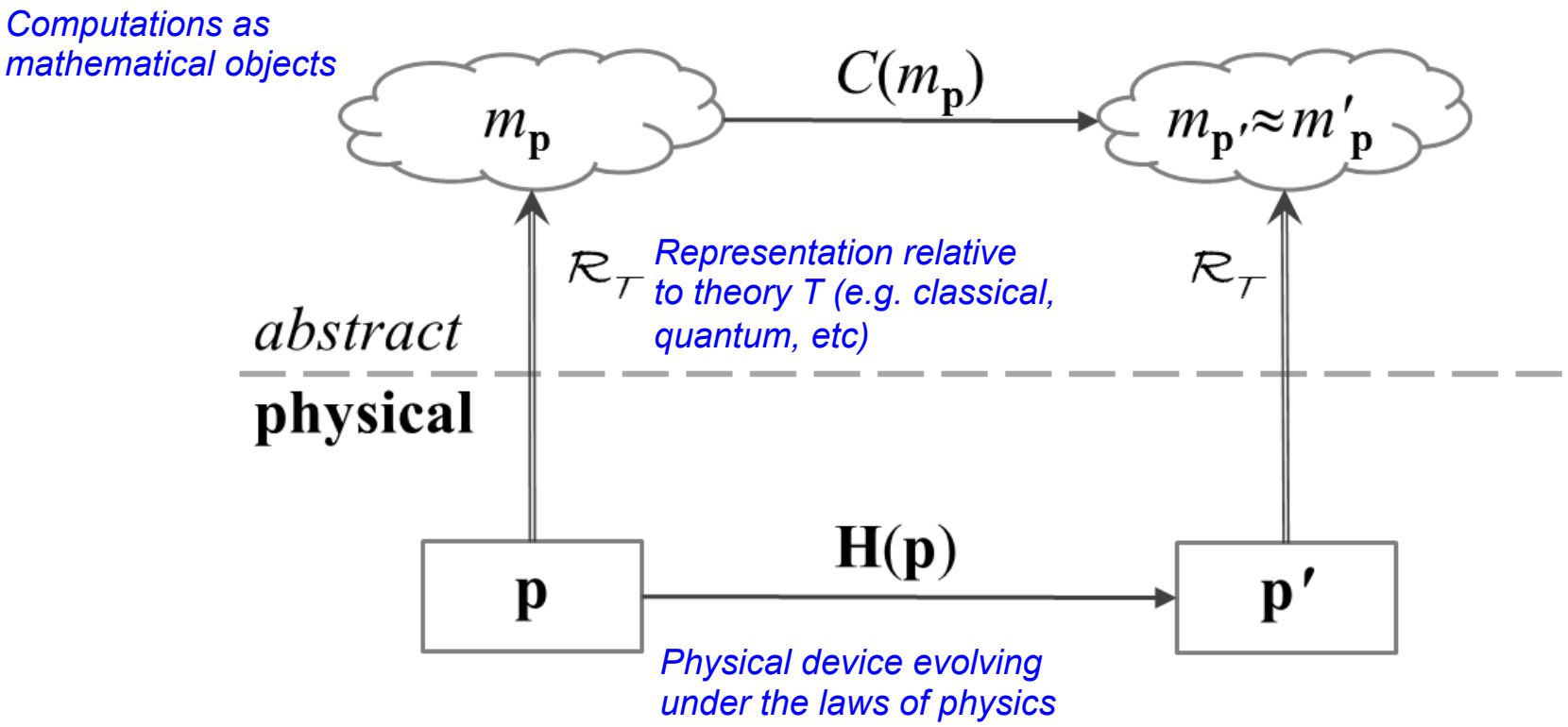
[1]*Clare Horsman, Susan Stepney, Rob Wagner, and Viv Kendon. When does a physical system compute? Proceedings of the Royal Society A, 470(2169):20140182, 2014.*

A “Sufficiently Commuting” Diagram



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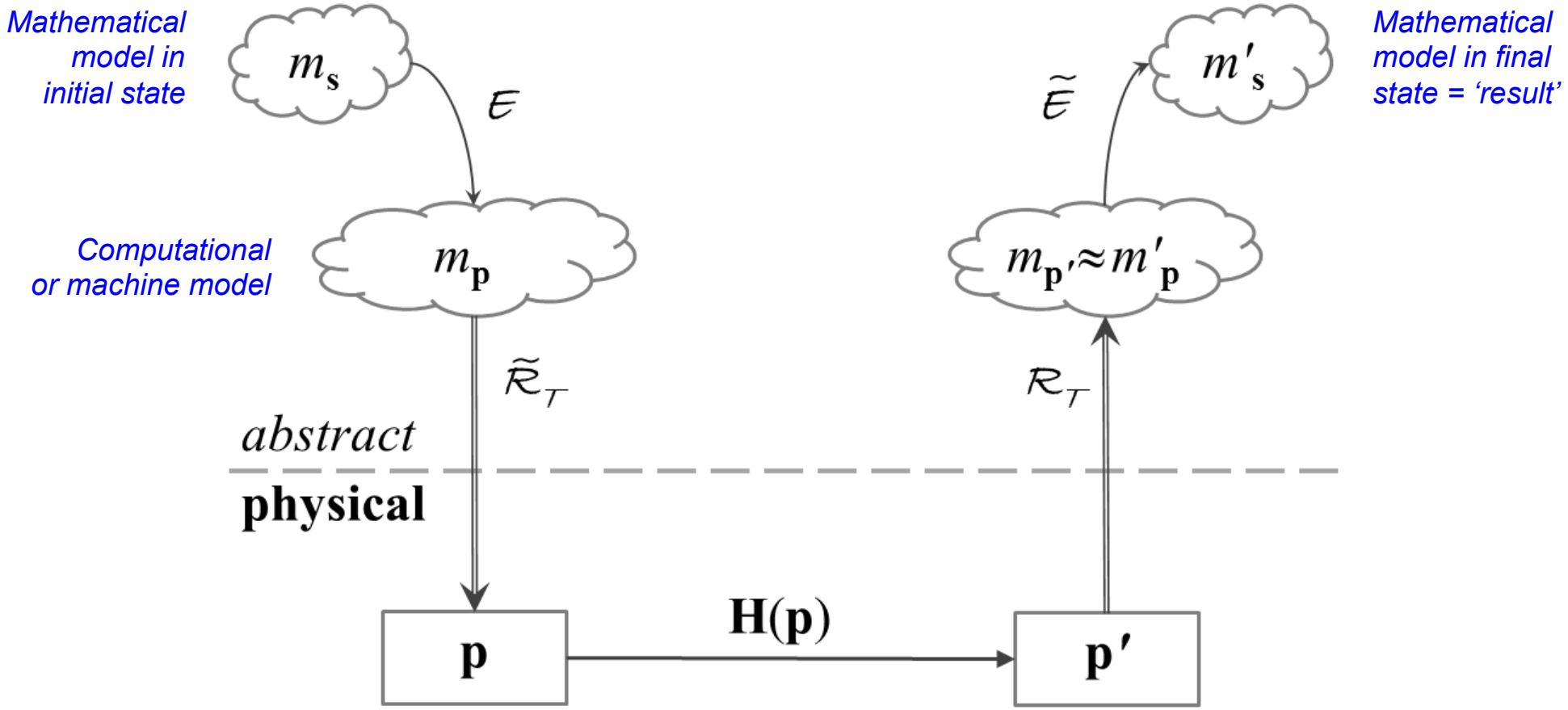
Clare Horsman, Susan Stepney, Rob Wagner, and Viv Kendon. When does a physical system compute? Proceedings of the Royal Society A, 470(2169):20140182, 2014.

A Computation



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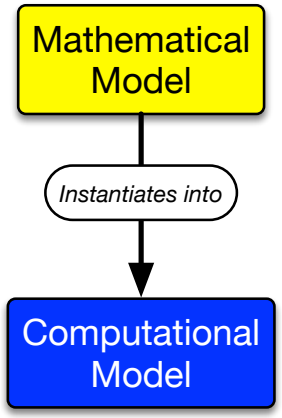
Clare Horsman, Susan Stepney, Rob Wagner, and Viv Kendon. When does a physical system compute? Proceedings of the Royal Society A, 470(2169):20140182, 2014.

BIOMICS Computational Framework

Starting with the Abstraction/Representation Theory perspective



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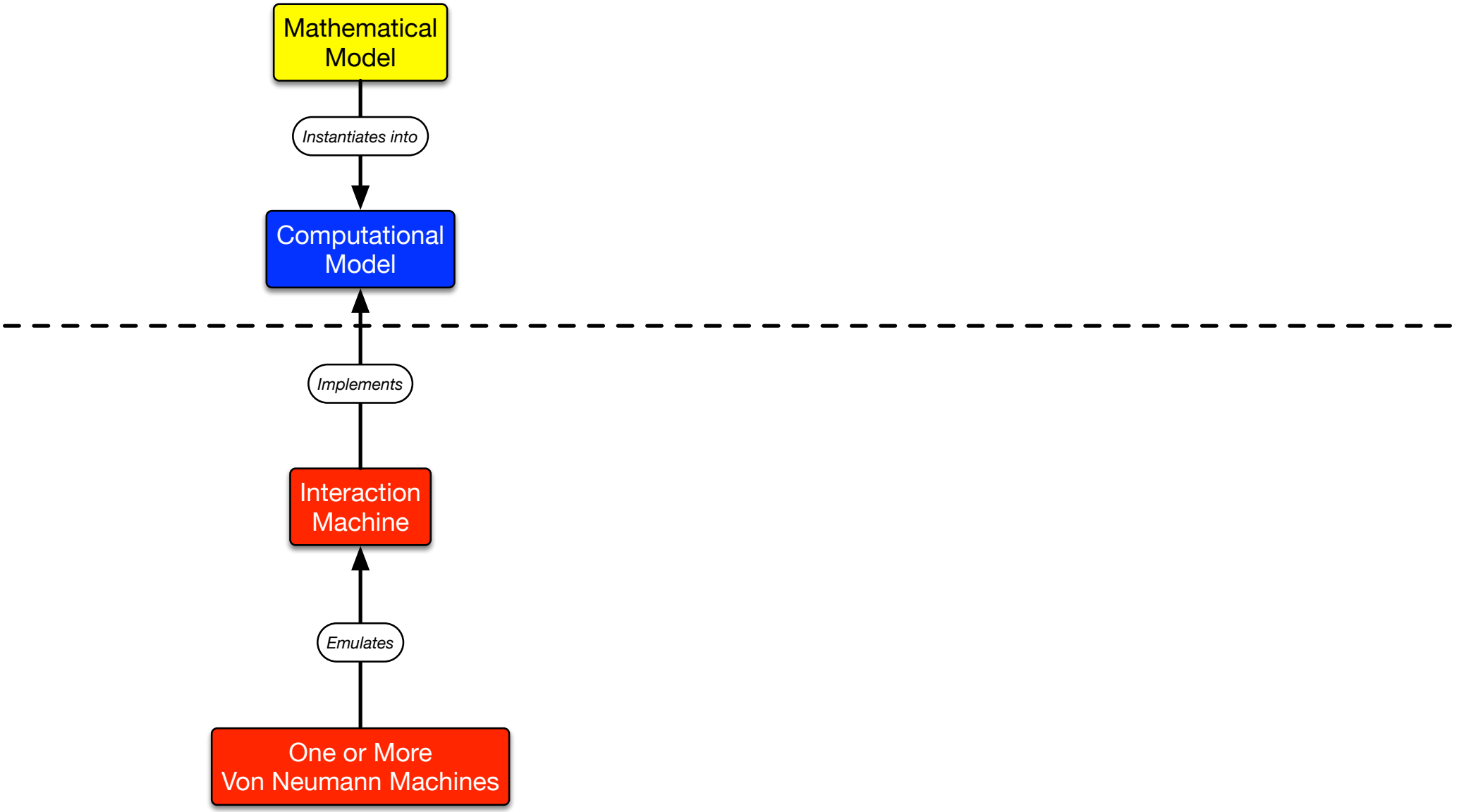
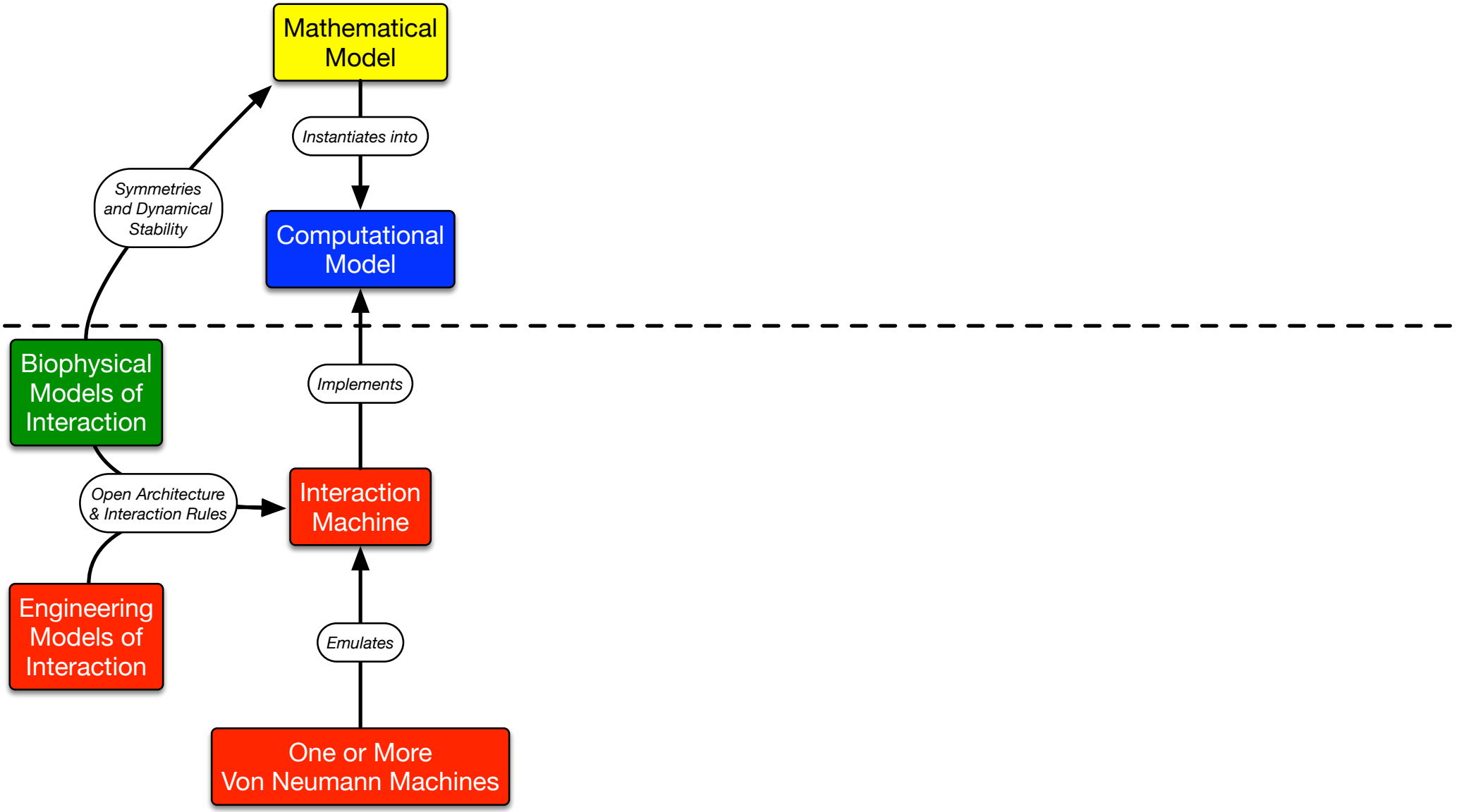
Adding an emulation layer in place of actual natural computation



BIOMICS Computational Framework

Creating new theory from biology, physics and engineering intuition



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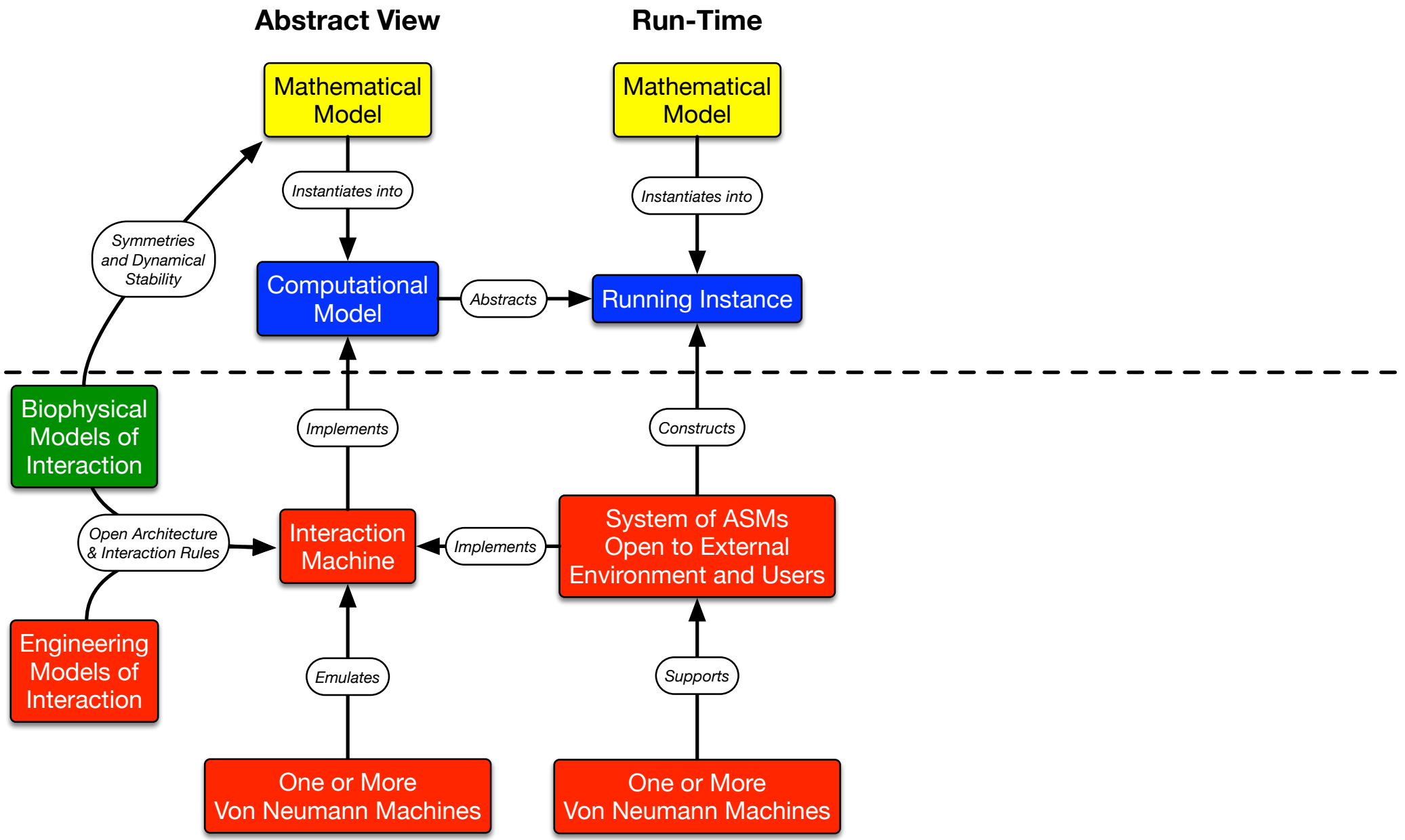
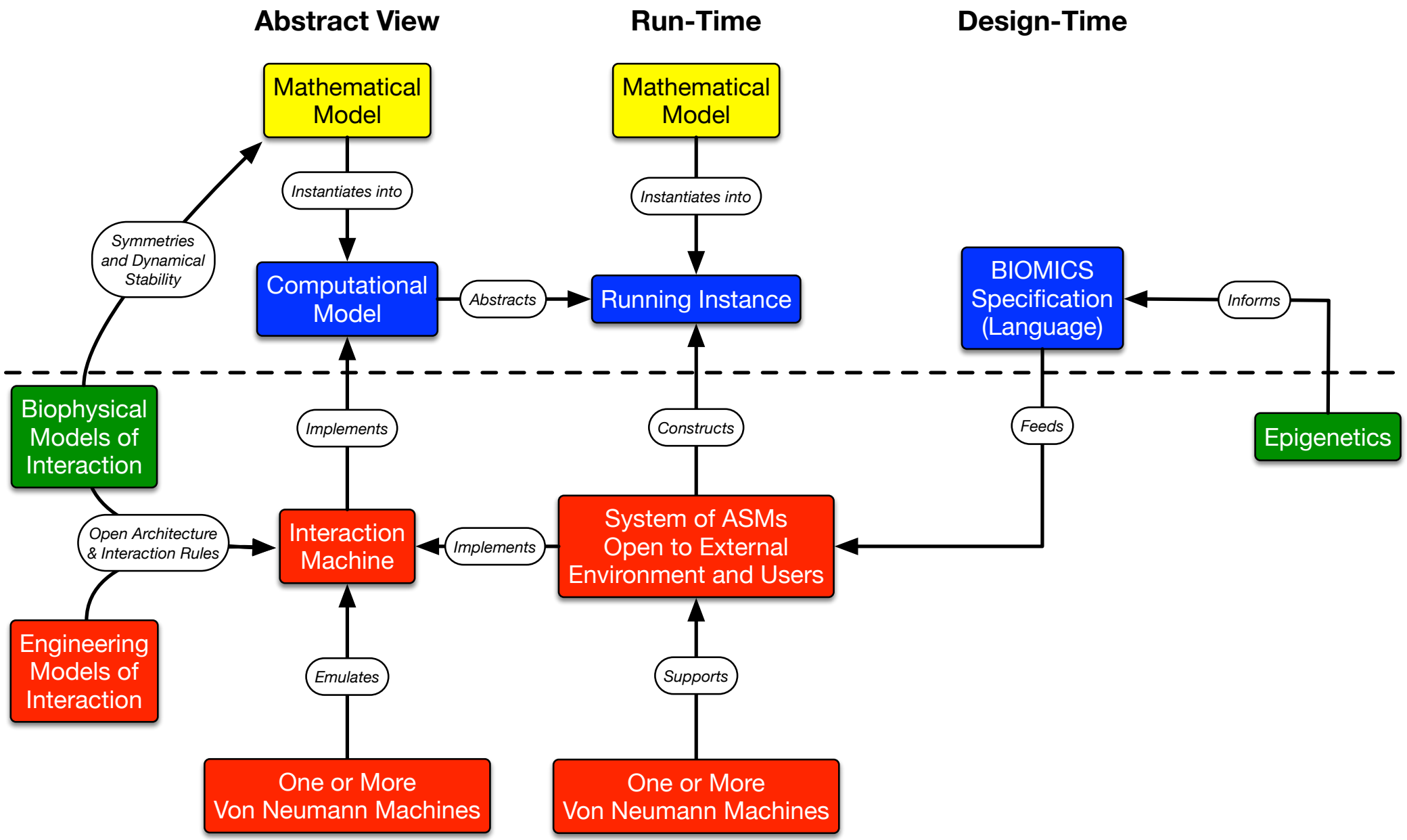
The run-time view



BIOMICS Computational Framework

More biology in the genotype-phenotype map: Still in progress!



Epistemological-Ontological Alignment in Constructive Computational Models

Epistemology:

- the study of knowledge
- what we know, or how we know if something is true
- *how knowledge is constructed*

Ontology:

- the study of reality, or what something ***is*** (‘The ontology of money’)
- what reality is, or how we know if something is “real”
- *how reality is constructed*

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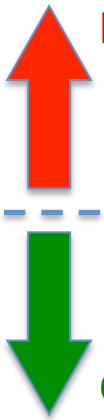
Ontology and Epistemology Not Aligned in Conventional Computing

Mathematical model	Evaluation of a mathematical function	*Knowledge is being constructed*
Computational model	Turing Machine	
Physical device	Von Neumann Machine (one or more)	*Reality is not being constructed: Machine is changing state but is not **itself** changing*



Epistemology

Ontology

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Ontology and Epistemology Aligned in Interaction Computing

Mathematical model	Non-linear constructive	*Knowledge is being constructed*
Computational model	Open system, Interacting Computational Components driven by external triggers	*Knowledge is being constructed, number of states is also changing*
Emulation of physical system	Interaction Machine	*'Reality' is being constructed: Machine is changing state **and is also creating new states***
Physical device	Von Neumann Machine (one or more)	*Reality is not being constructed: Machine is changing state but is not **itself** changing*

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Conclusion

- From the observations discussed and the arguments presented, it appears that to achieve self-organizing computations within an IC framework some kind of isomorphism should be sought between ontogenetic construction of order and an analogous constructive mathematical framework

- The new mathematics is likely to require the integration of:

  - non-linear dynamical systems and symmetry analysis
  - statistical/stochastic processes and stability analysis (through the quasi-potential)
  - algebraic automata theory
  - fractal-like recursive, iterative, and generative maps of simple specification rules
  - coalgebraic formulation of epigenetic interactions of the fractal-like specification rules
  - a computational framework that can handle all this (probably Abstract State Machines)
  - a category theory framework to glue everything together in a rigorous mathematical way

Interaction Computing = Non-linearly interacting, recursive, fractal and coalgebraic ASMs?

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