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Multimodels and multisimulation

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A motivational questions

Is it worth attempting to conceive

- new modeling formalisms?
- new simulation formalisms?

If your answers are "NO"
It might be interesting to know the reasons.

AI (Artificial Intelligence) Winter (1974–80 and 1987–93)

Sir Michael James Lighthill,
(23 January 1924 – 17 July 1998),
a British applied mathematician

http://en.wikipedia.org/wiki/AI_winter

A thesis:

Appropriate formulation (i.e., modeling) of physical and social phenomena may improve:

- our conception, perception, and understanding of reality and
- the way solutions may be developed.

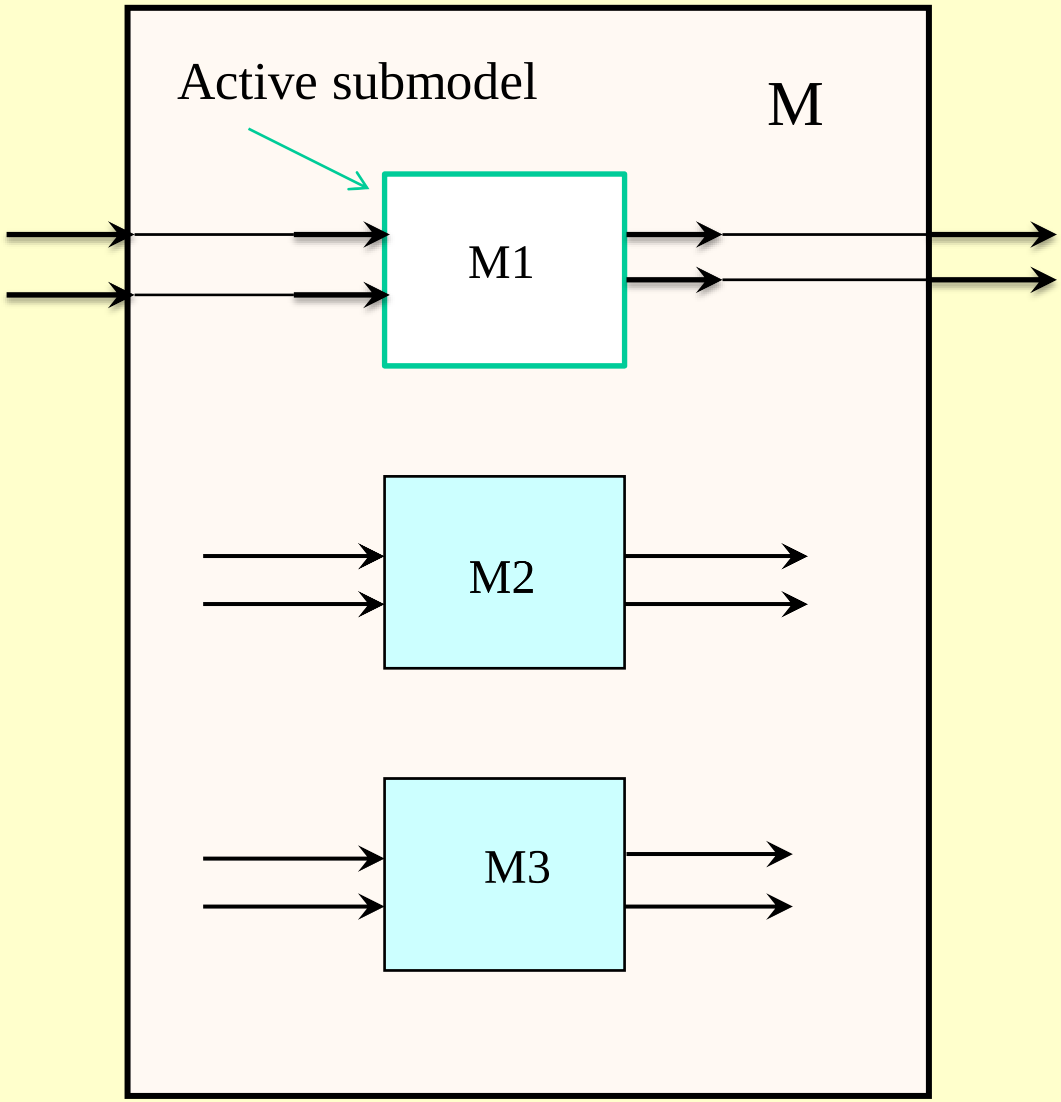
Multimodels

A multimodel

- can encapsulate different aspects of a model; and
- consists of several **submodels**.

At any time, at least one (i.e., one, some, or all) of the submodels is active.

A multimodel:



At least one submodel is active at a time to represent the multimodel.

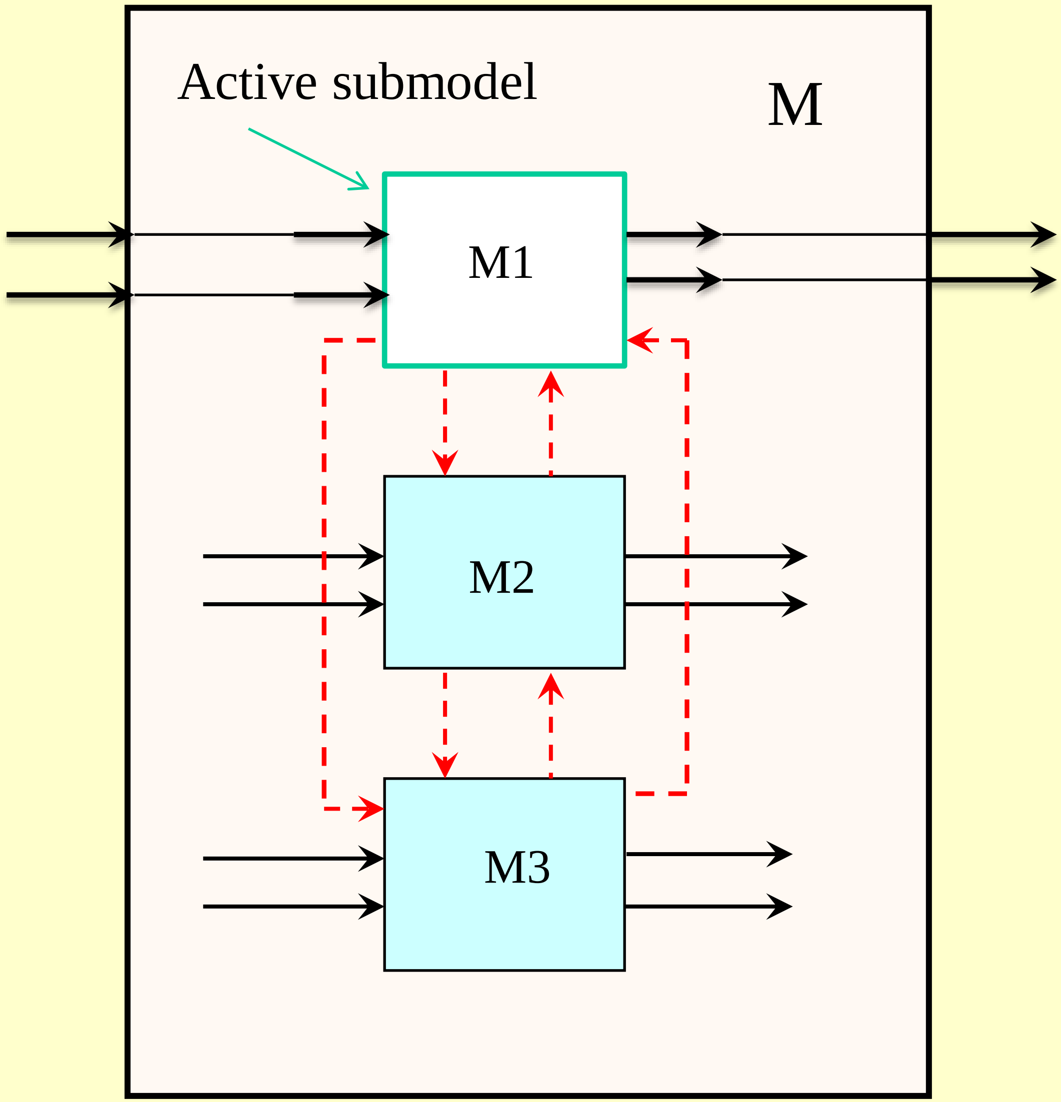

Input / output

The concept of coupling of simulation models was first introduced in the GEST language:

Ören, T.I. (**1971**). *GEST: A Combined Digital Simulation Language for Large-Scale Systems*. Proceedings of the Tokyo 1971 AICA (Association Internationale pour le Calcul Analogique) Symposium on Simulation of Complex Systems, Tokyo, Japan, September 3-7, pp. B-1/1 - B-1/4.

Hence, coupling of active submodels of a multimodel was easy to conceive.

A multimodel:



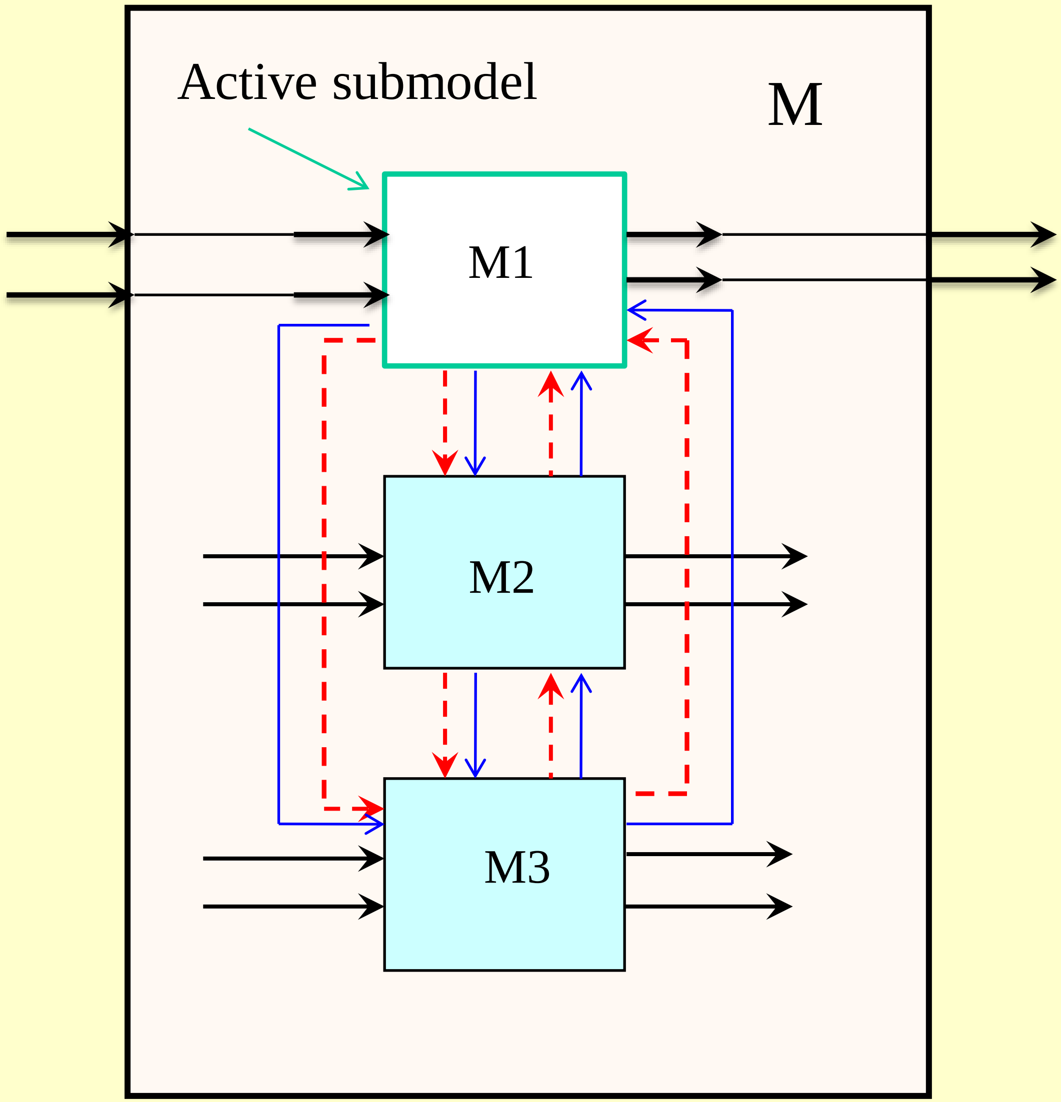
At least one submodel is active at a time to represent the multimodel.

Input / output

Control of activation of submodels

(conditions to be specified in each submodel)

A multimodel:



At least one submodel is active at a time to represent the multimodel.

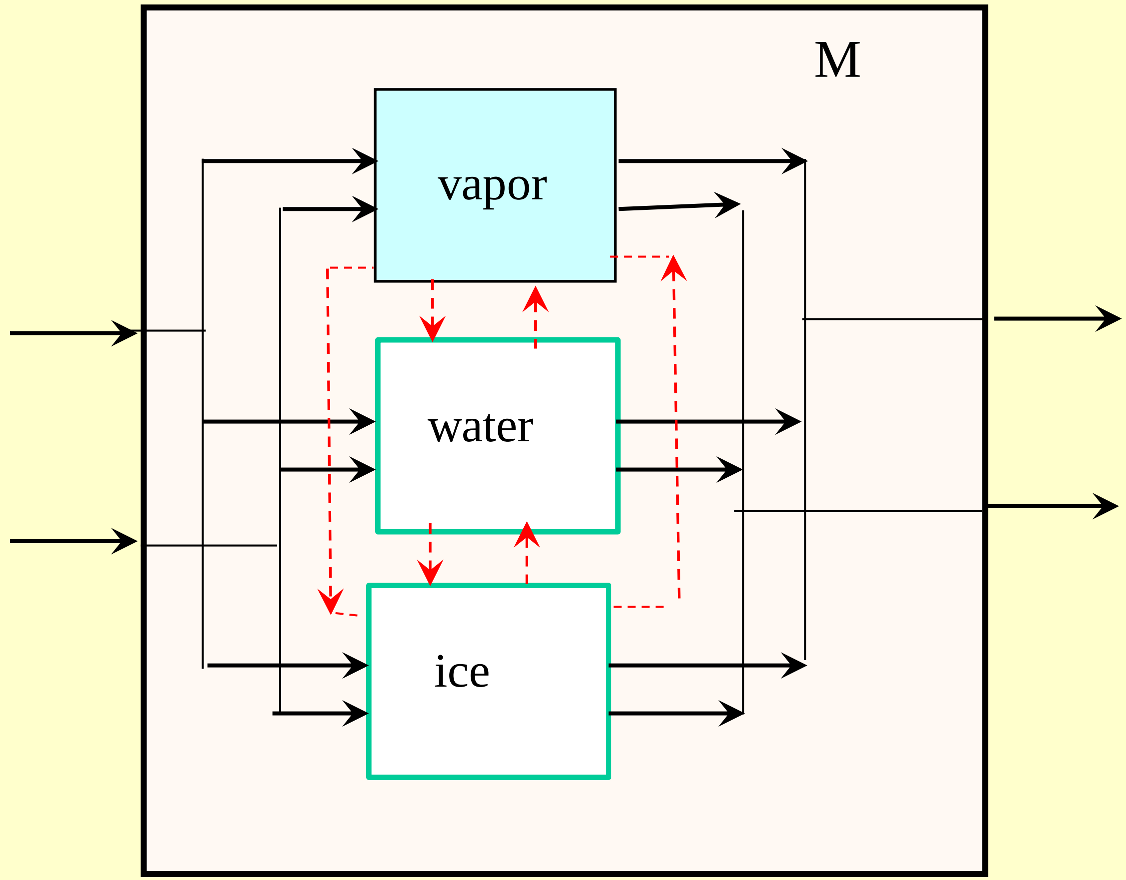
Input / output

Control of activation of submodels

Possible flows of entities between submodels

A type of multimodel - ***multiaspect model***
(e.g., ice, water, vapor)

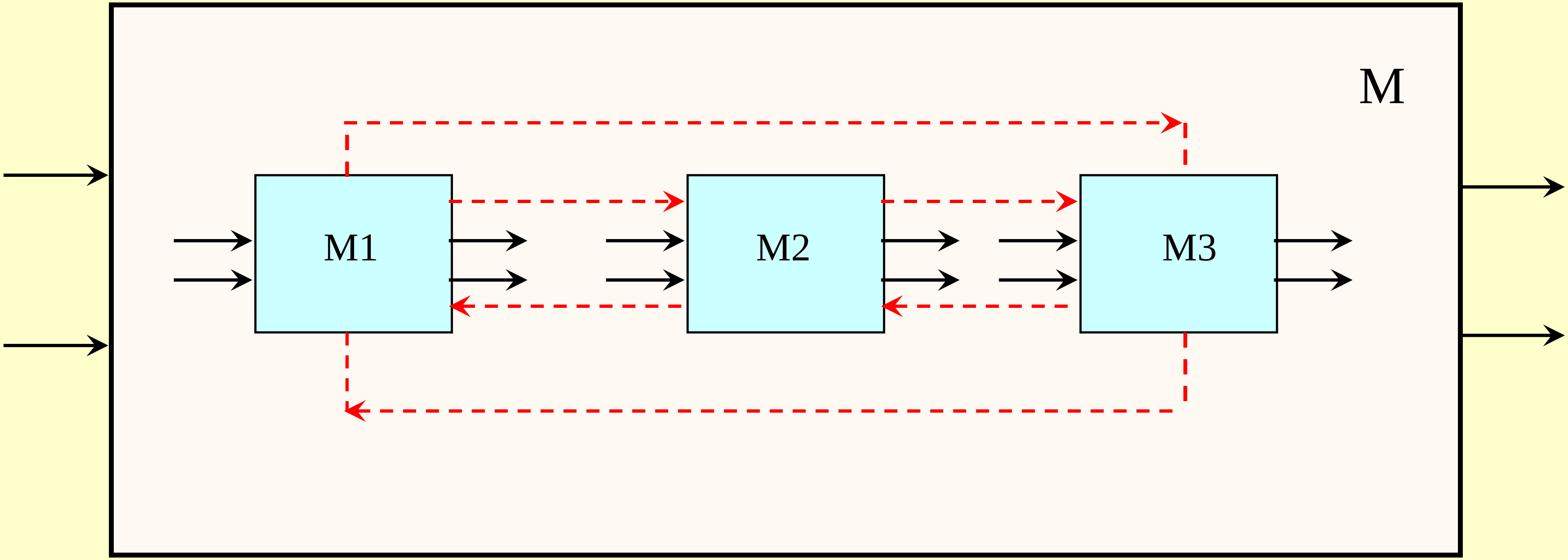
More than one submodel can exist at the same time
with possible flows of entities (e.g., mass) between submodels



A *multiaspect model*: (a different representation) (e.g., ice, water, vapor)

More than one alternate model can exist at the same time

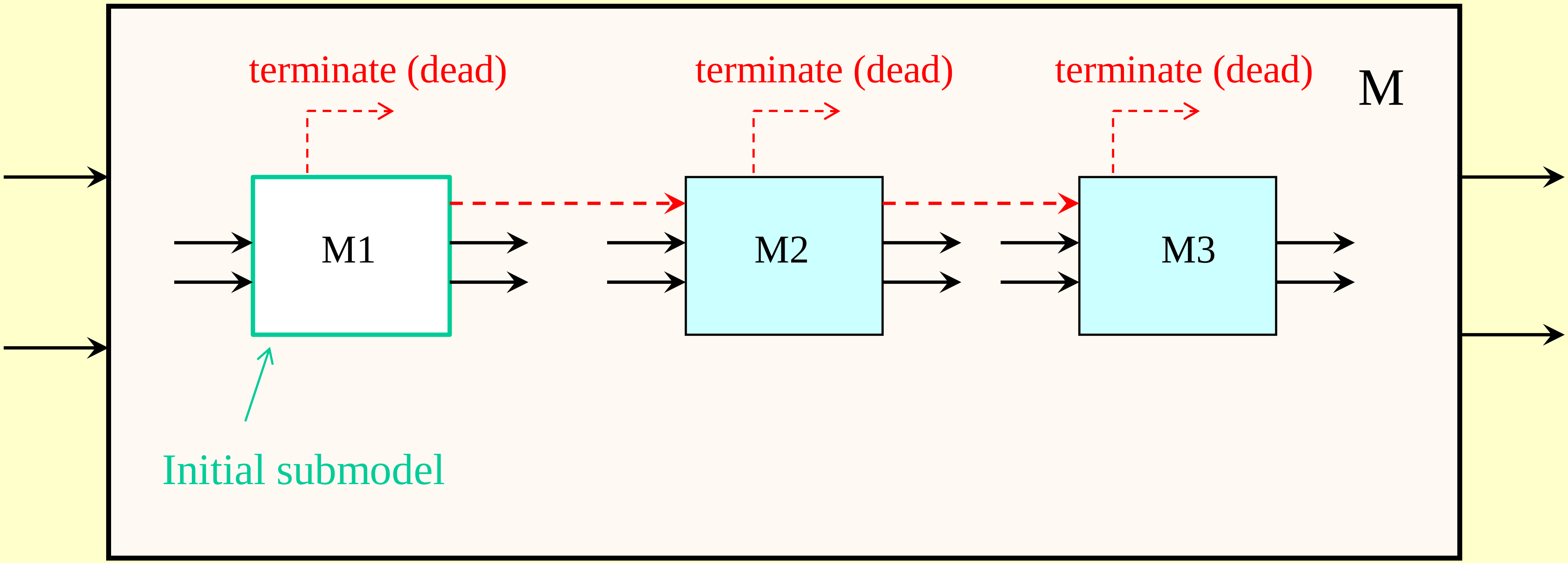
with possible flows of entities (e.g., mass) between submodels



An example - A ***metamorphic model***:
(e.g., egg, larva, pupa, butterfly)

Only one submodel is active at a given time.

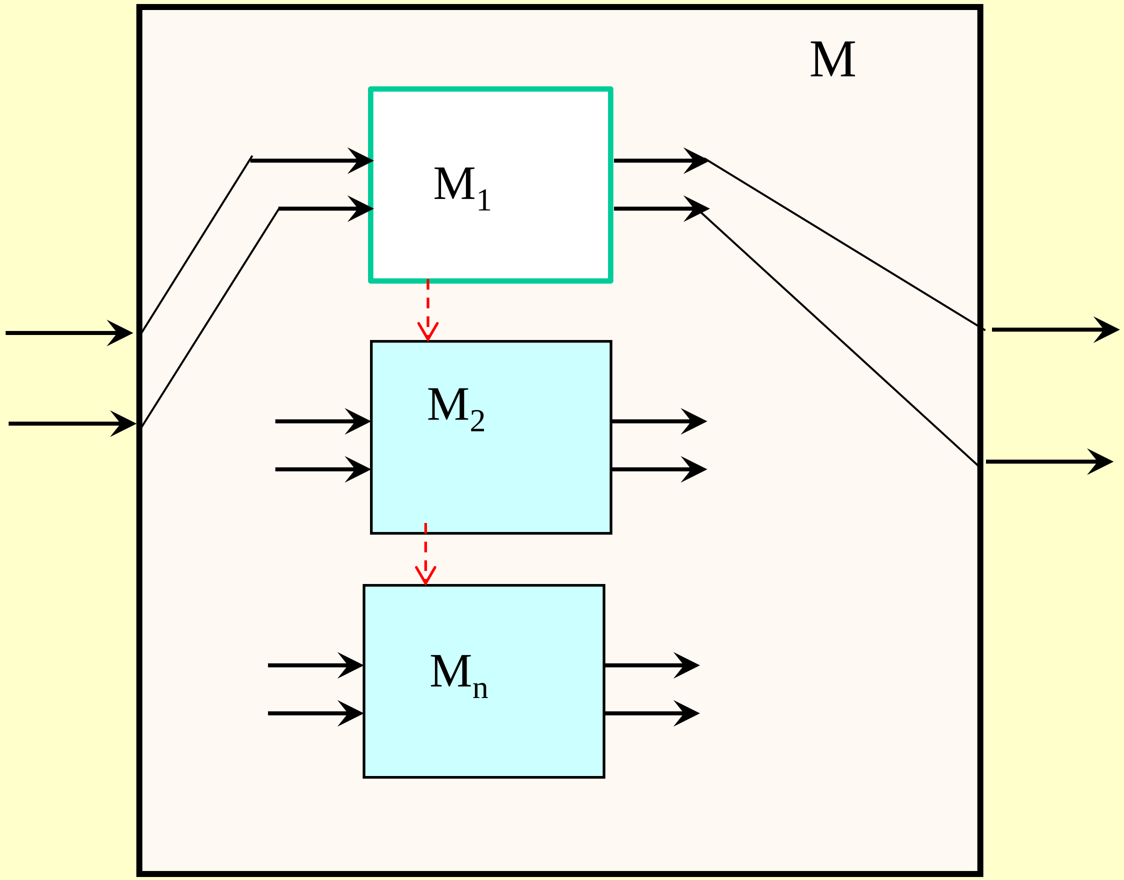
There is a predefined sequence for the alternate submodels.



A type of multimodel - ***metamorphic model*:** (e.g., egg, larva, pupa, butterfly)

There is a predefined **"sequence"** for the alternate models.

Another representation to ease depiction of the **coupling of submodels**



How the concepts are developed?
A personal experience:

- In 1970, I developed the **first** system theory-based model specification language for **continuous systems:**

Ören, T.I. (**1971**). *GEST: General System Theory Implementor, A Combined Digital Simulation Language*. Ph.D. dissertation, University of Arizona, Tucson, AZ.

Ören, T.I. (**1971**). *GEST: A Combined Digital Simulation Language for Large-Scale Systems*. Proceedings of the Tokyo 1971 AICA (Association Internationale pour le Calcul Analogique) Symposium on Simulation of Complex Systems, Tokyo, Japan, September 3-7, pp. B-1/1 - B-1/4.

(& many other publications)

How the concepts are developed?
A personal experience:

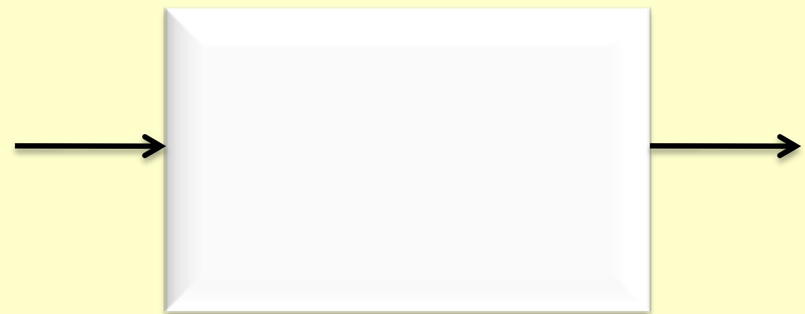
Ören, T.I. (**1984**). GEST - A Modelling and Simulation Language Based on System Theoretic Concepts. In: Simulation and Model-Based Methodologies: An Integrative View, T.I. Ören, B.P. Zeigler, M.S. Elzas (eds.). Springer-Verlag, Heidelberg, Germany, pp. 281-335.

A GEST Model

Static structure
  Input variables . . .
  State variables . . .
  Output variables . . .

  Constants . . .
  Parameters . . .
  Auxiliary parameters . . .
End static structure

Static section:
- **Declarations**



State transition function
  x’ = . . .
End state transition function
Output function
  u = . . .
End output function

Dynamic section:
- **State transitions**
- **Output functions**

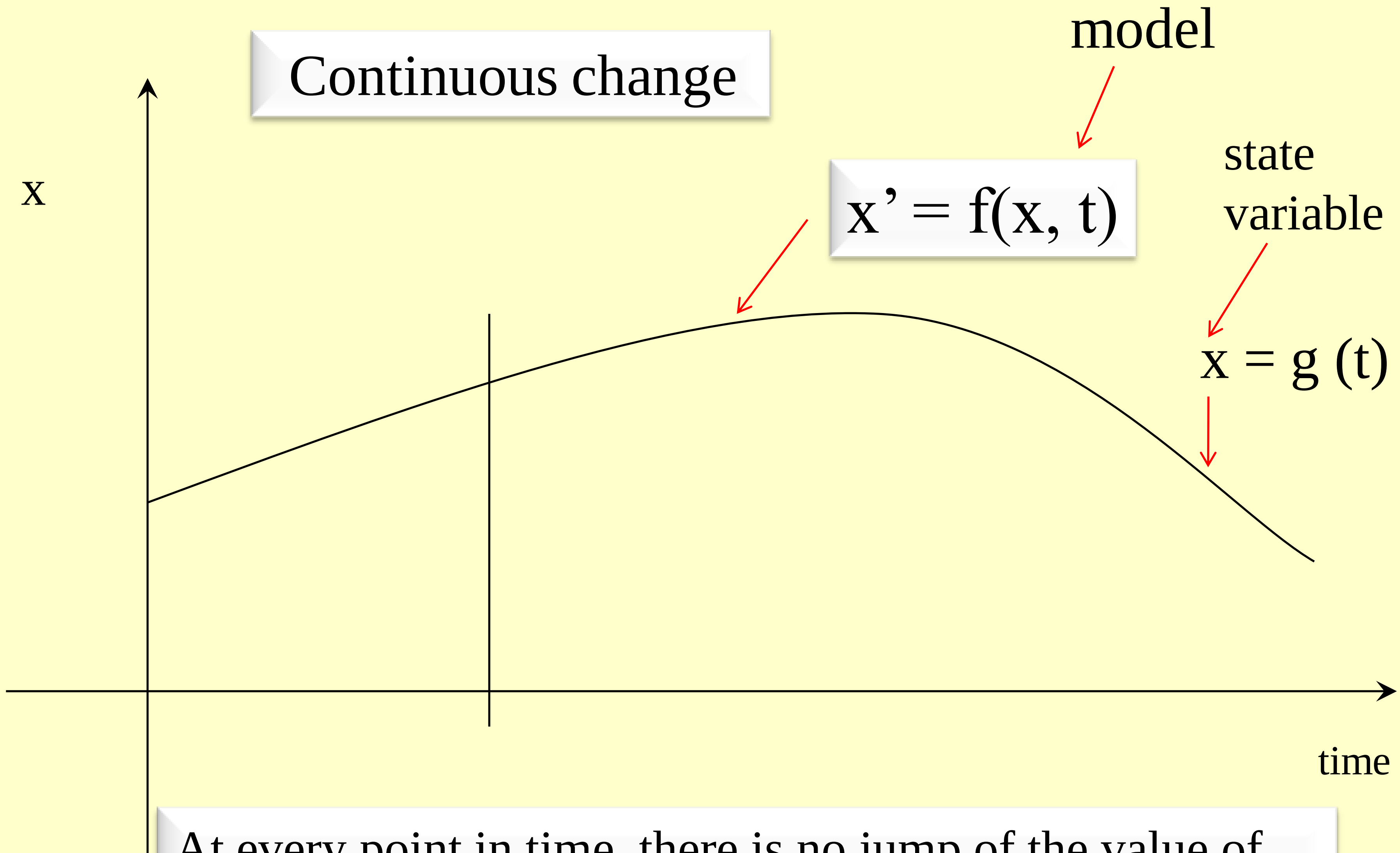
In the 1980s, I was involved in the development of two integration algorithms for piece-wise continuous i.e., **discontinuous systems**:

Birta, L.G., Ören, T.I., Kettenis, D.L. (**1985**). *A Robust Procedure for Discontinuity Handling in Continuous System Simulation*, Transactions of the Society for Computer Simulation, 2:3, 189-205.

Ören, T.I., Ma Jihu (**1986)**. *An Adaptive Order Discontinuity Algorithm for Simulation of Ordinary Differential Equations*. In: Proceedings of JSST (Japan Society for Simulation Technology) conference on Recent Advances in Simulation of Complex Systems, Tokyo, Japan, July 15-17, 1986, pp. 283-288.

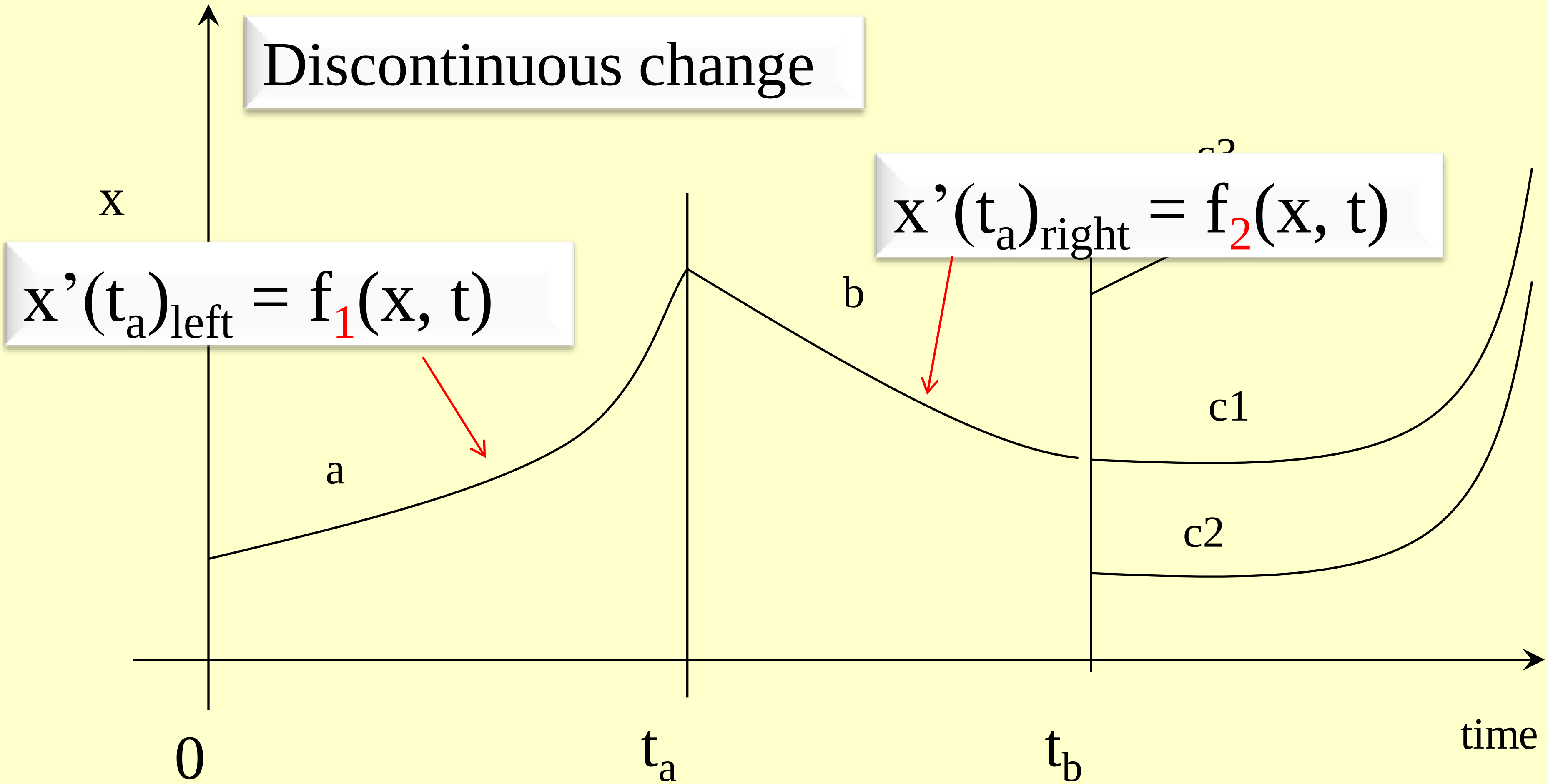
- While working on the development of the integration algorithms for *discontinuous systems*, I remarked that **there are two types of discontinuities** that can occur ***separately*** or ***together*** at a given instant of time.

Continuous change



At every point in time, there is no jump of the value of **the state variable** & the **derivative** from left and right.

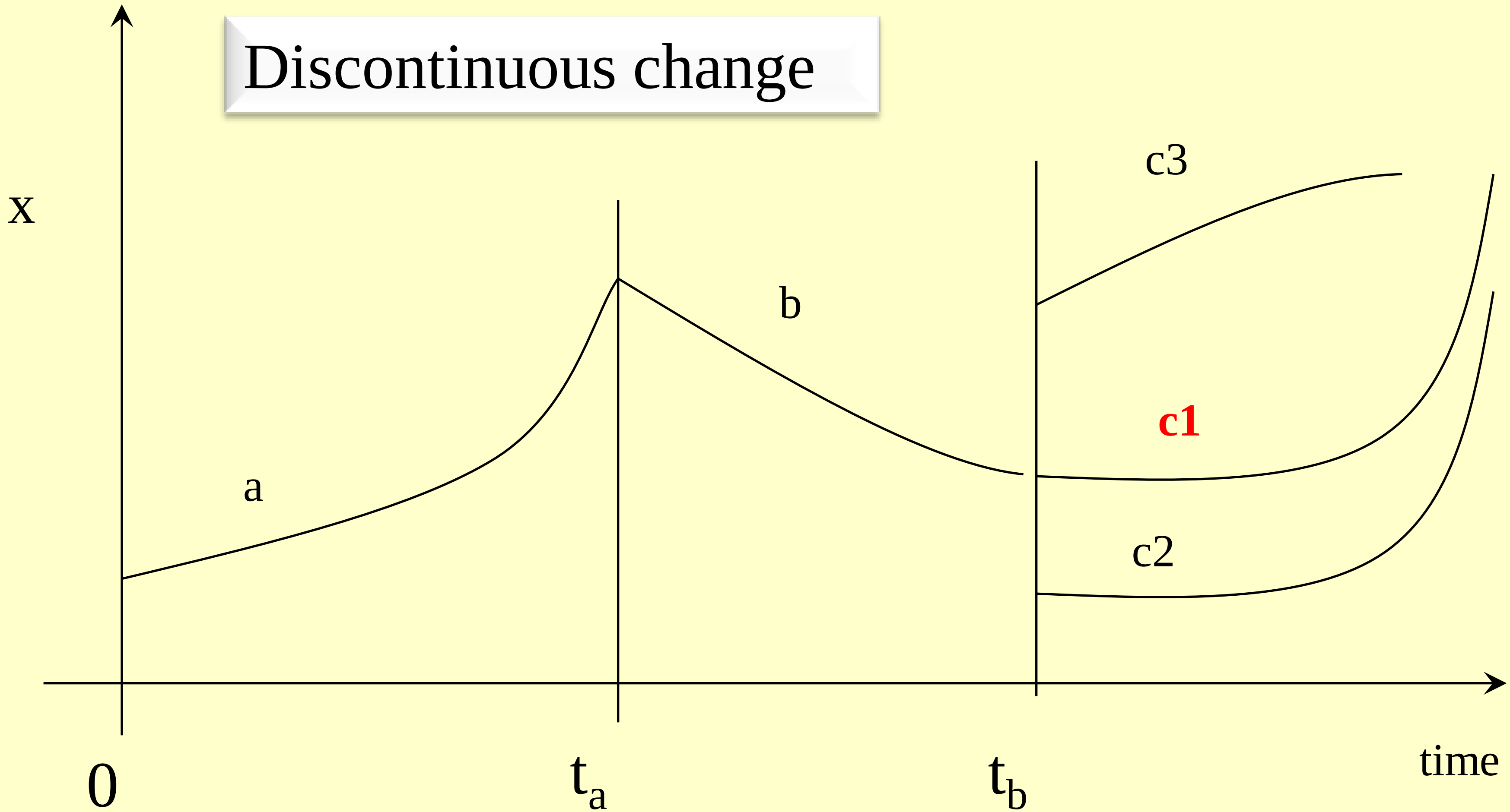
Discontinuous change



At t_a derivative from left and derivative from right are different;
i.e., different models are used (model is updated at t_a).

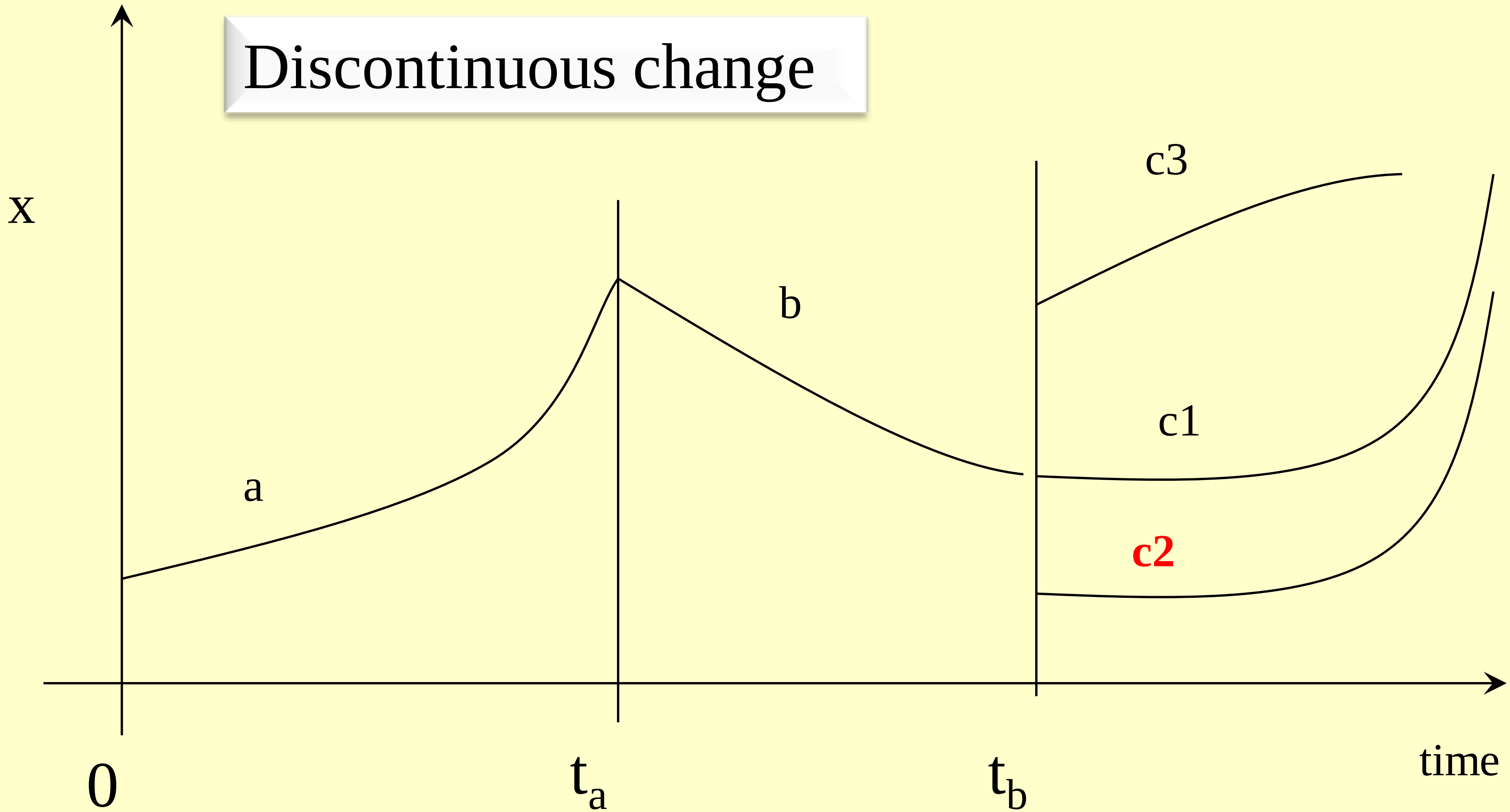
Hence there is a **model discontinuity** which necessitates a "**model update**."

Discontinuous change



At $t_{b,}$ **c1**: (supposing that derivative from left and derivative from right are the same) there is **no** discontinuity.

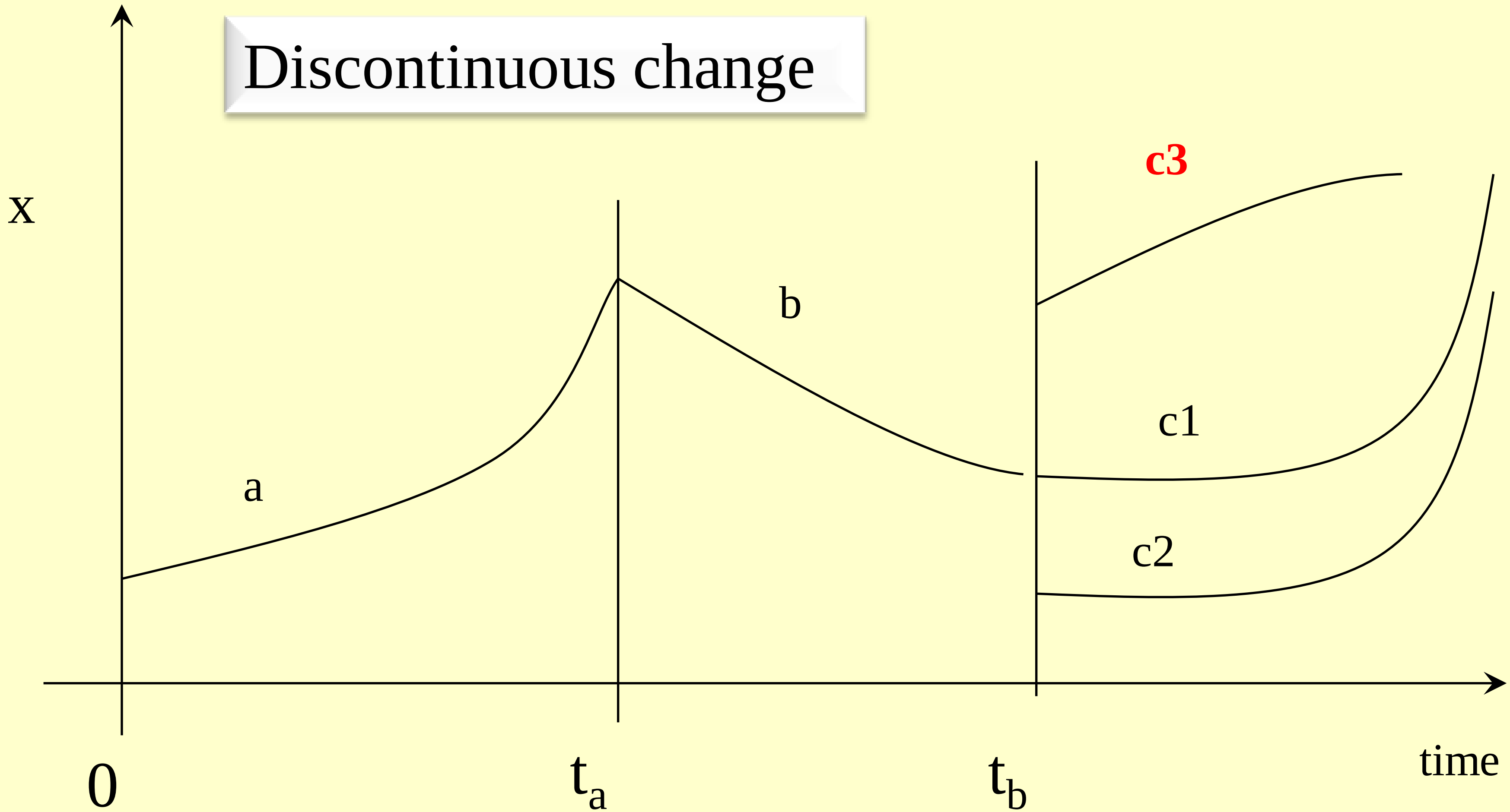
Discontinuous change



At $t_{b,}$ **c2**: (supposing that derivative from left and derivative from right are the same) there is a discontinuity. At t_b, same model is used but state variable needs to be **re-initialized**.

There is an **initialization discontinuity** **(a jump discontinuity).**

Discontinuous change



At $t_{b,}$ c3: derivative from left and derivative from right are different & values of the state variable are different. At $t_{b,}$ two types of **discontinuity exist, namely** **model discontinuity** and **initialization discontinuity**.

In late 1980s and early 1990s, I generalized the "**model update**" concept to **model switching**, i.e., **switching from a model to another**:

Ören, T.I. (**1987**). ***Model Update***: *A Model Specification Formalism with a Generalized View of Discontinuity*. In: Proceedings of the Summer Computer Simulation Conference, Montreal, Quebec, Canada, 1987 July 27-30, pp. 689-694.

Ören, T.I. (**1991**). ***Dynamic Templates*** *and Semantic Rules for Simulation Advisors and Certifiers*. In: Knowledge-Based Simulation: Methodology and Application, P.A. Fishwick and R.B. Modjeski (Eds). Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 53-76.

The essence of **model update**:

Static section: declarations

Dynamic section:

Model update section:

A submodel

Conditions under which a submodel activates another one, i.e., model switches

As a further development:

Switchable model & **switchable simulation** concepts lead to **switchable understanding**.

(non-dogmatic understanding

(emphatic understanding)

(flexible understanding)

Ören, T.I. (**2000** – Invited Opening Paper). *Understanding: A Taxonomy and Performance Factors*. In: D. Thiel (ed.) Proc. of FOODSIM'2000, June 26-27, 2000, Nantes, France. SCS, San Diego, CA, pp. 3-10.

Multivision understanding as opposed to single vision understanding (which may be dogmatic understanding) may lead to **switchable understanding**:

In **switchable understanding** any one of the following possibilities may be used alone or in combination:

- Have more than one meta-model and switch them based on the context (in multisimulation, several meta-models can be used simultaneously.)
- Use perceptions of different granularity.
- Use different granularity of mappings between the meta-models and the perceptions for understanding.

Back to multimodels

Yilmaz, L. and T.I. Ören (**2005**). *Discrete-Event Multimodels and their Agent-Supported Activation and Update*. In Proceedings of the Agent-Directed Simulation Symposium of the Spring Simulation Multiconference (SMC'05), pp. 63-72, San Diego, CA, April 2005.

Evolutionary models:

Evolution is irreversible change in an open system.

An evolutionary model can be represented by a series of variant models M_i.

A taxonomy **multimodels** is offered at:

Yilmaz, L. and Ören, T.I. (**2004**). ***Dynamic Model Updating*** *in Simulation with* ***Multimodels****: A Taxonomy and a Generic Agent-Based Architecture*, Proceedings of SCSC 2004 - Summer Computer Simulation Conference, July 25-29, 2004, San Jose, CA., pp. 3-8.

<table>
<tr><th>Based on</th><th colspan="4">Additional Criteria</th><th>Type of multimodel (MM)</th></tr>
<tr><td rowspan="8">Structure of Sub-models</td><td colspan="3" rowspan="2">**Number** of submodels active at a given time</td><td>Only one</td><td>**Single aspect MM (Sequential MM)**</td></tr>
<tr><td>2or more</td><td>**Multiaspect MM**</td></tr>
<tr><td rowspan="6">Variability of structure</td><td colspan="3">Static</td><td>**Static-structure MM**</td></tr>
<tr><td rowspan="5">Dynamic
(Dynamic-structure MM)
(Variable-structure MM)</td><td rowspan="2">Number of submodels</td><td>Extensible</td><td>**Extensible MM**</td></tr>
<tr><td>Depends on model’s stage</td><td>**Multistage MM**</td></tr>
<tr><td rowspan="3">Alterations of sub-models</td><td>No</td><td>**Non-mutational MM**</td></tr>
<tr><td rowspan="2">Yes</td><td>**Mutational MM**</td></tr>
<tr><td>**Evolutionary MM**</td></tr>
</table>

<table>
<tr><th>Based on</th><th colspan="4">Additional Criteria</th><th>Type of multimodel (MM)</th></tr>
<tr><td rowspan="6">Behavior (activ-ation)
of sub-models</td><td rowspan="4">Nature of knowledge
to activate submodels</td><td colspan="3">Constraint-driven</td><td>Constraint-driven MM (Adaptive MM)</td></tr>
<tr><td rowspan="2">Pattern-directed (Pattern-directed MM)
(Metamorphic MM)</td><td rowspan="2">Submodel selection is cyclic</td><td>No</td><td>Acyclic MM</td></tr>
<tr><td>Yes</td><td>Cyclic MM</td></tr>
<tr><td colspan="3">Goal-directed</td><td>Goal-directed MM (Exploratory MM)</td></tr>
<tr><td rowspan="2">Location of knowledge
to activate submodels</td><td colspan="3">Within the MM
(Internal activation of submodels)</td><td>Active MM
(Internally activated MM)</td></tr>
<tr><td colspan="3">Outside the MM
(External activation of submodels)</td><td>Passive MM
(Externallyactivated MM)</td></tr>
</table>

In 2001, I generalized the

“**model update**” and “**model switching**” concepts to lead to:

- ***multisimulation*.**

Ören, T.I. (**2001** – Invited contribution). *Towards a Modelling Formalism for Conflict Management*. In: Discrete Event Modeling and Simulation: A Tapestry of Systems and AI-based Theories and Methodologies. H.S. Sarjoughian and F.E. Cellier (eds.), Springer-Verlag, New York, pp. 93-106.

Yilmaz, L., T.I. Ören, and N. Ghasem-Aghaee (**2006**). *Simulation-Based Problem Solving Environments for Conflict Studies: Toward Exploratory Multisimulation with Dynamic Simulation Updating*. *Simulation, and Gaming Journal.*

Emergence

Emergent state

Emergent relation

Models with emergent states and / or relations

Multimodels with emergent states and / or relations

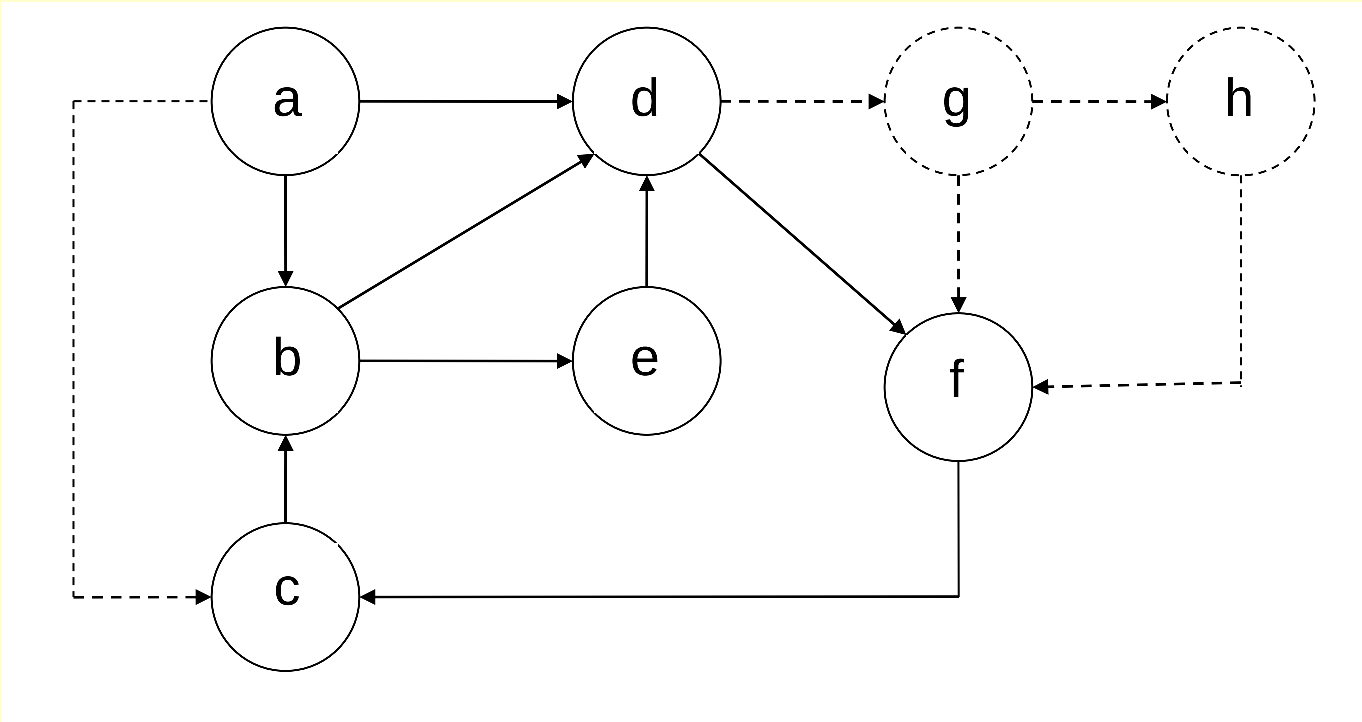
Emergence is: "the arising of novel and coherent structures, patterns and properties during the process of self-organization of complex systems."

State machines:

Mealy machines

Moore machines

Emerged states and emerged transitions (which can have fuzzy representations) in a state machine



Emergent states

Emergent transitions

Multistage state machines:

Multistage model based on state machine formalism.

Emerging conditions may necessitate:

- emerging states
- emerging transitions

Some other multistage modeling formalisms:

Petri nets

Fuzzy logic models

DEVS

Endomorphic models (ghost models, introspective models)

(Intelligent) Agents

Multiagents (similar to a multimodel),
metamorphic agent, multiaspect agent

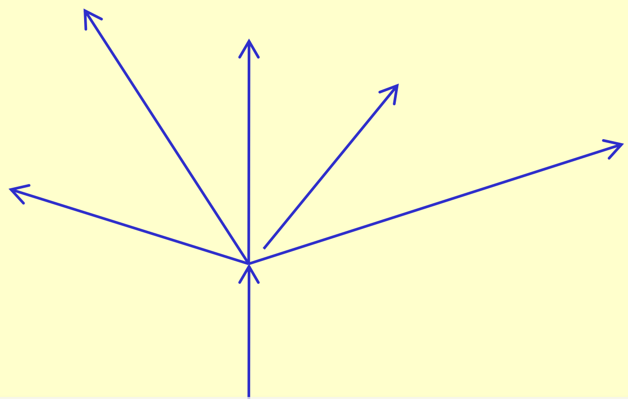
Learning models

Yilmaz, L., A. Lim, S. Bowen, and T.I. Ören (**2007**). *Requirements and Design Principles for Multisimulation with Multiresolution, Multistage Multimodels*. Proceedings of the 2007 Winter Simulation Conference, pp. 823-832, December 9-12, Washington, D.C.

Now, let’s see:

Multisimulation

At a crossroad:



- At a crossroad several roads to take.
- Similarly, after an interruption of the simulation study, several simulations can be performed by using **different models** and/or **experimental conditions**.
- The simulations could be sequential; however, there are advantages of making them simultaneous.
  (time advantage, resource-sharing un real system)

Multisimulation:

Simulation run

- experimentation with a dynamic model

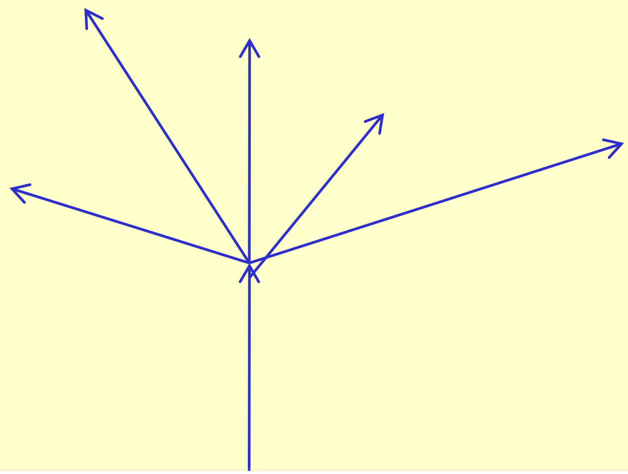
Simulation study

- a collection of simulation runs with the same dynamic model

Multisimulation

- simulation with several aspects of realities (experimentation with **multistage** models)
  - simultaneous
  - sequential

Multisimulation can also enhance predictive displays (by allowing several simultaneous simulations)



An agent-based system may also automatically select the “best” command (input) to the system

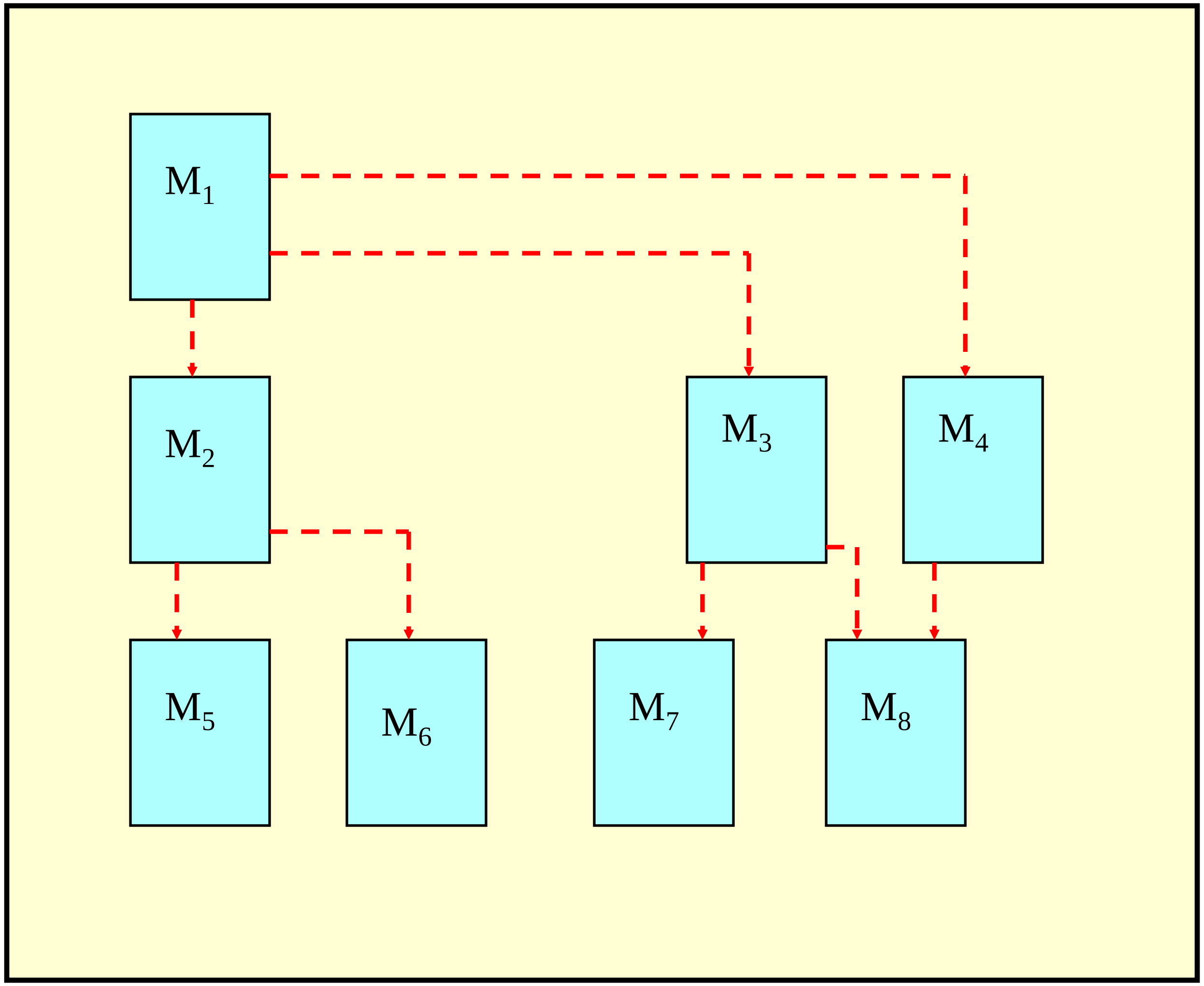
Multisimulation

In some aspects of social system dynamics, during a simulation, completely new conditions may **emerge** and accordingly,

- a simulation study may need to be interrupted,
- models and/or experimental conditions may need to be replaced by a new ones and then
- the simulation study would resume.

- In some cases, at the update instant of the simulation study, one may want to continue with two or more models under same or different experimental conditions.

Multistage models:



M_1

M_1M_2

$M_1M_2M_5$

$M_1M_2M_6$

$M_1M_2(M_5, M_6)$

M_1M_3

$M_1M_3M_7$

$M_1M_3M_8$

$M_1M_3(M_7, M_8)$

M_1M_4

$M_1M_4M_8$

Toward **Multisimulation**
with Dynamic Simulation Updating

- **Multisimulation** (or multisim, for short) is simulation of several aspects of reality in a study.

It includes:

- simulation with (sequential) **multimodels**,
- simulation with **multiaspect models**, and
- simulation with **multistage models**.

- **Simulation with sequential multimodels** allows computational experimentation with several aspects of reality, sequentially.
- **Simulation with multiaspect models** (or **multiaspect simulation**) allows computational experimentation with more than one aspect of reality *simultaneously*.

Simulation with multistage models allows branching of a simulation study into several simulation studies

• **Multistage simulation**, can allow a novel way to perceive and experiment with several aspects of reality as well as exploring conditions affecting transitions between several aspects of systems, especially social systems.

The following few slides are from:

Yilmaz, L. and Ören, T.I. (2004). Dynamic Model Updating in Simulation with Multimodels: A Taxonomy and a Generic Agent-Based Architecture, Proceedings of SCSC 2004 - Summer Computer Simulation Conference

- **Multimodeling** formalism inspired the development of several methodologies, including
  - combined simulation [Preahofer 1992],
  - FSA-controlled multimodeling [Fishwick and Zeigler 1992], and
  - MOOSE [Cupert and Fishwick 1997].
- Yet, we are still scratching the surface of what is possible with the very basic dynamic model update concept.

- The **taxonomy** presented in this paper is an indicator for the potential for various types of multimodels.

- The generic **agent-supported** approach presents a reasonable strategy to realize multimodel simulators.

However, opportunities exist for more research to identify intricate details of:

- **observing** the simulation state,
- **reason** to qualify models for update,
- facilitate run-time model **rebinding**, and
- **plan** for goal-directed activation of submodels.

Thank you for your attention!

Q & A