SEN9110 Simulation Masterclass
Lecture 12: Multi-Resolution Simulation

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Brightspace: SEN9110

1.

Multi-Resolution Modeling (MRM)

Multi-Resolution Modeling

The researcher on Multi-Resolution Modeling is Paul K. Davis from RAND Corporation in the USA

What is resolution?

- fidelity
- level of detail?
- accuracy?
- precision?

Here: resolution is **level of detail** of a (sub)model.

Resolution

Model may be high resolution in one respect and low in another:

- entities
- attributes
- processes
- temporal
- spatial
- behavior
- etc.

Definition

Davis and Bigelow (1998) define multi-resolution modeling as follow:

1. Building a single model with different levels of resolution for a problem;
2. Building an integrated family of consistent models with different levels of resolution for a problem; or
3. Both

Requirements for Multi-Resolution Models

(Yilmaz et al., 2007)

1. The knowledge regarding its configuration and representation must be decoupled from the model.
2. The concurrent interactions at multiple levels of resolution must be combined consistently
3. The state of entities at different levels of resolution has to be consistent.
4. The behavior of the entities can be altered from within.
5. Independence of the constraints regarding when and under what conditions the consistency of the elements of families of submodels in a multiresolution model be enforced.
6. Dynamic loading and linking of the entities into the run-time environment of the simulation.
7. Construction of the state can be continued from a specific state after an update operation.
8. The existence of a mechanism for changing the structure and behavior of the model dynamically.
9. Definitions of behavioral resolutions must be flexible to facilitate analysis that is independent of an implementation.
10. Mechanisms to decide when and under what conditions to replace existing models with a successor or alternative are important in order to perform the multi-resolution models.

Need for both hi-res and lo-res models

(Davis, Report WR-224, 2005 – see background literature)

Low-Resolution	High-Resolution
Early design	Detailed design
Using low-resolution knowledge	Using high-resolution knowledge
Analysis responding to high-level questions	Narrow, in-depth analysis for accuracy, precision, or detail
Reasoning and comprehension with high-level variables	Reasoning and comprehension at more atomic level of phemonena
Informing, calibrating, or summarizing hi-res work	Informing, calibrating, or explaining lo-res work
Abstracting "big picture"	Simulating reality

Taxonomy of multimodels (1)

Based on structure

<table>
<tr><th>Based on</th><th colspan="4">Additional Criteria</th><th>Type of multimodel (MM)

(Synonyms are represented within parentheses)</th></tr>
<tr><td rowspan="8">Structure of submodels</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>2 or more</td><td>Multiaspect MM</td></tr>
<tr><td rowspan="6">Variability of structure

(variability of number of submodels)</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 submodels</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>

Yilmaz, WSC2007

Taxonomy of multimodels (2)

Based on behavior

Yilmaz, WSC2007

<table>
<tr><th>Based on</th><th colspan="4">Additional Criteria</th><th>Type of multimodel (MM)</th></tr>
<tr><td rowspan="6">Behavior (activation) of submodels</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">Sub-model 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 (Externally activated MM)</td></tr>
</table>

Approaches for MRM

(Rabelo et al, 2015)

Many different approaches:

- Hierarchical modeling
- Middleware regulation
- Regulator as a federate
- Resolution converter
- Selective viewing
- Aggregation / Disaggregation
- Multi-Resolution Events (MRE)
- Hybrid disaggregation/MRE
- Agent-based

Aggregation / Disaggregation

- **Aggregation is relatively easy**:
  define an aggregation operator that aggregates state / entities / behavior over time or over another variable
  - Example: from individual cars per lane to vehicle density per lane

- **Disaggregation is hard**:
  extra information is needed to disaggregate as certain information was erased by the aggregation operator
  - Example: to reconstruct cars from a density function, information about types of cars (e.g., car, truck), speed profiles, O/D, etc. have to be recreated

Linking aggregate and disaggregate models

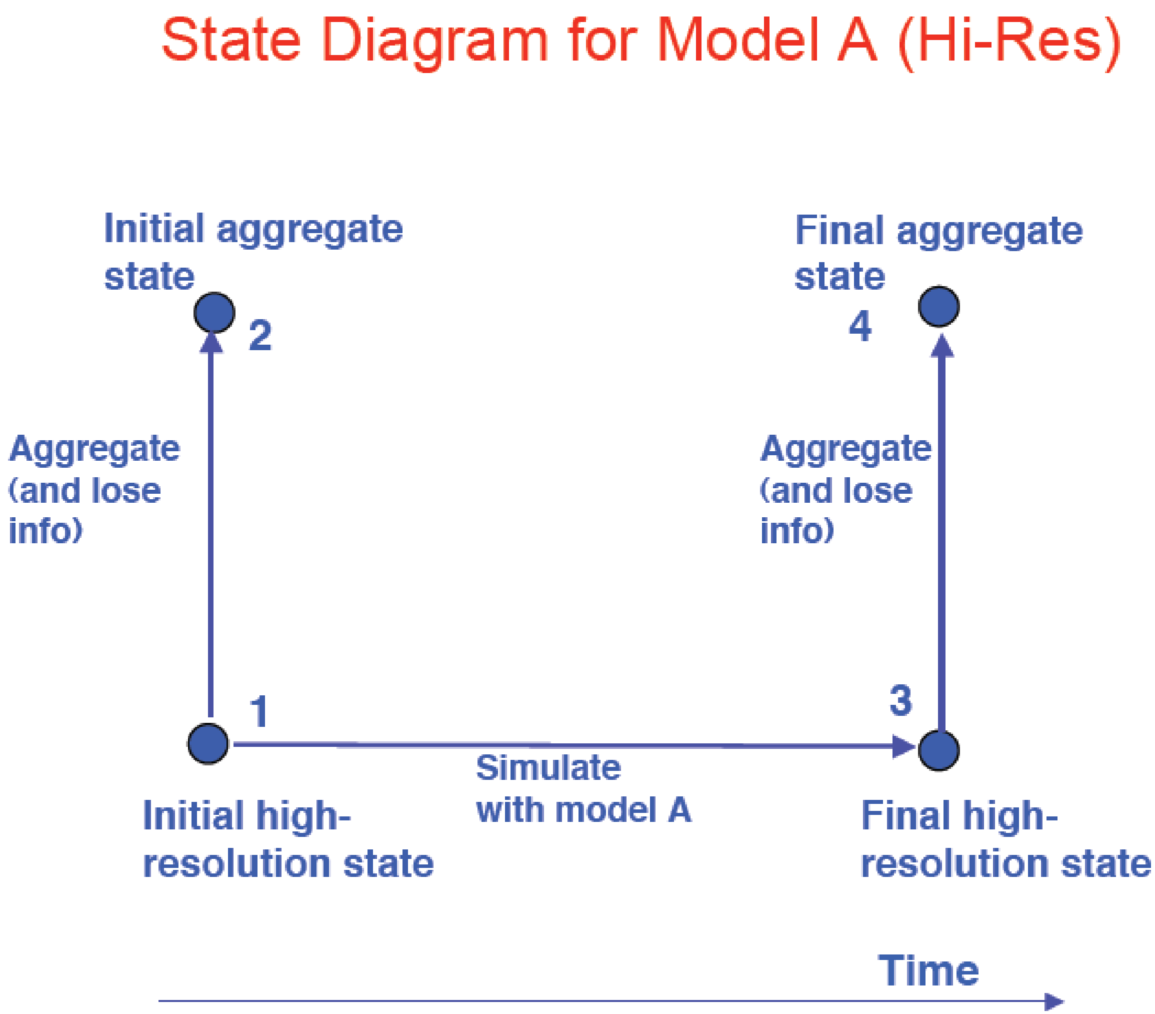
But what is even harder is **correct** connections between aggregate and disaggregate models:

- aggregation and disaggregation have to happen in simulation time
    - Example: when a car leaves the detailed model, its presence has to be added to the density function
    - Example: but when do we disaggregate a car **from** the density function?

- the **connection** between the aggregate model and disaggregate model has to show realistic behavior as well
    - Example: when there is a traffic jam in the disaggregate model, the density function has to implement the kickback in the aggregate model
    - Example: same the other way around -> slow uptake in aggregate model

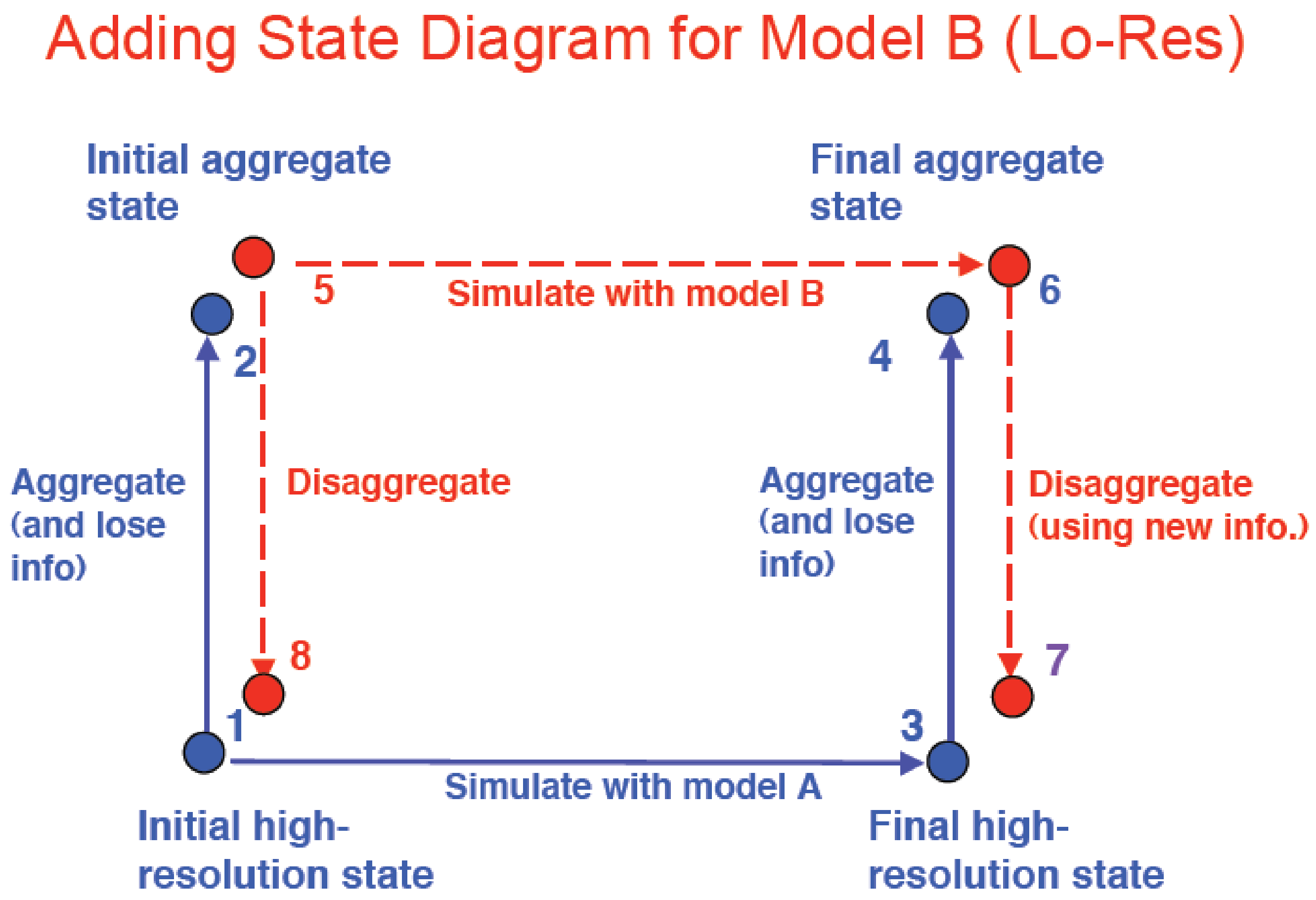
Checking correct implementation (1)

(Davis, Report WR-224, 2005 – see background literature)



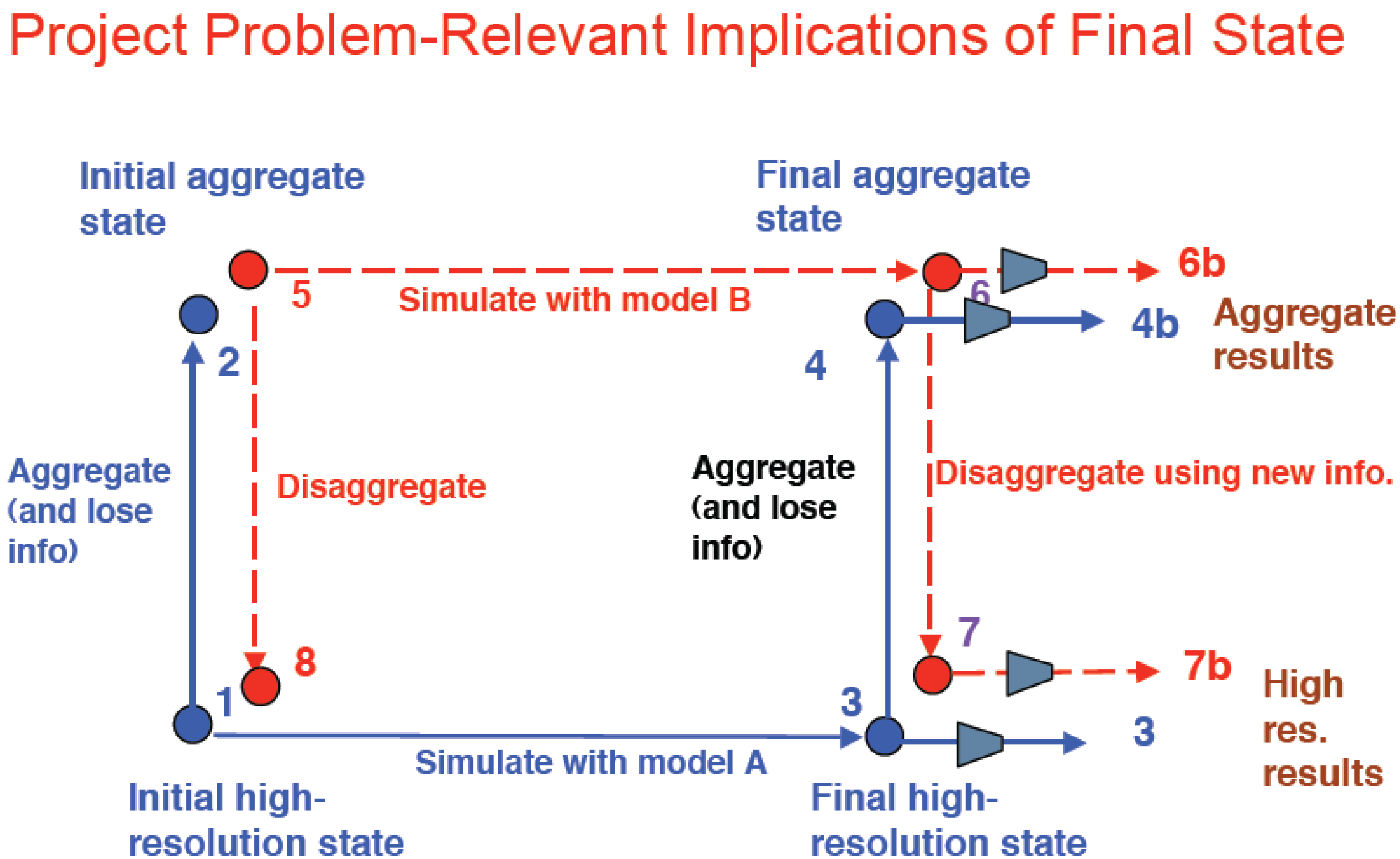
Checking correct implementation (2)

(Davis, Report WR-224, 2005 – see background literature)



Checking correct implementation (3)

(Davis, Report WR-224, 2005 – see background literature)



Weak consistency: 4b = 6b + ignorable error in relevant “experimental frame”
Strong consistency: 3 = 7b + ignorable error in relevant “experimental frame”

Conclusions

When linking (sub)models in hierarchical simulation or in distributed simulation:

- study the resolution of the models
- study the resolution of the entities, attributes, behavior, ...
- provide conversion functions for aggregation / disaggregation where necessary
- provide additional information for disaggregation functions
- check whether behavior has to be channeled through the interfaces to implement correct behavior
- test whether the dis/aggregation functions are correct by cross-validating as illustrated by Davis

In many cases **resolution between (sub)models is different!**

2.

Data Assimilation into Simulation Models

Data assimilation

- Data about **parts** of the state
- Not necessarily state variables themselves
- Observed at intervals or at events
- Errors in observations
- Missing values

Data assimilation methods

For <u>continuous</u> models

- Kalman filter most used method

For <u>discrete</u> models

- Many based on Monte Carlo
- **Particle filtering** the most promising method
  - multiple simulation runs in parallel (particles)
  - spread for the state variables
  - when observation comes in: resample around the particle(s) that best predicted the observation (<u>importance sampling</u>)
  - introduce enough spread in the particles to:
    - account for error in the observation
    - account for drift / behavior / state change in the model

Example (thesis Yubin Cho, EPA 2019)