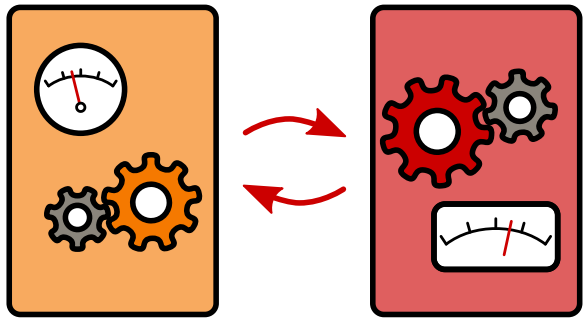
Multi-Scale Agent Environments

A method for coordinating unrelated space-time topologies in multi-agent, multi-scale simulations

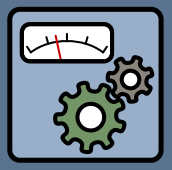
J. Luke Scott

Friday 13th September, 2013

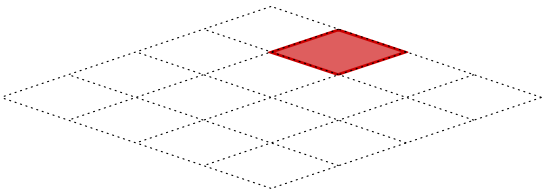


The Problem of **Scale Mediation**:

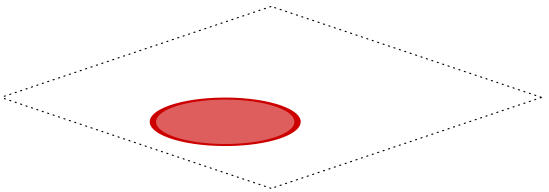
- Agents **observe** and **interact with** each other
- Agents have **different views** of space and time
- Differing views must be **integrated**
- Elephant example
- Definitions: **Scale** and **Scale Mediation**



Agent A



Agent B



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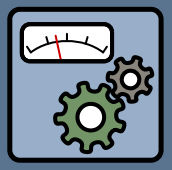

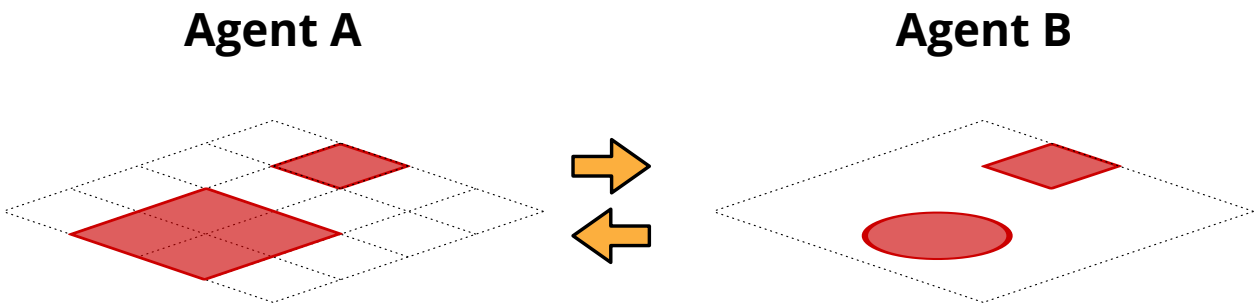

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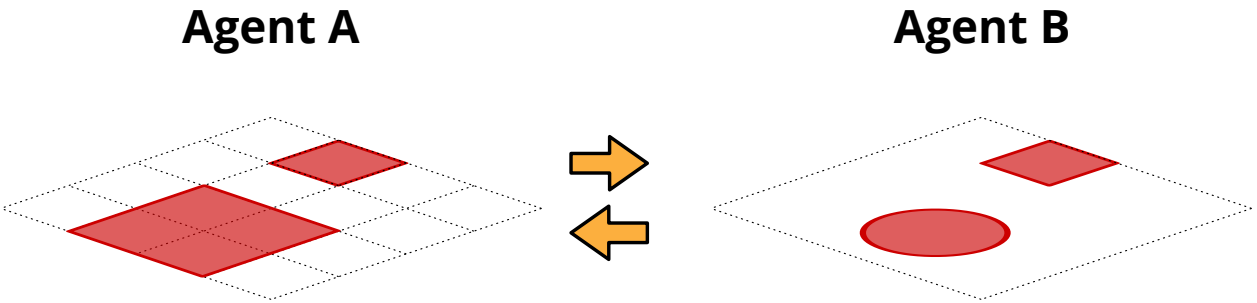

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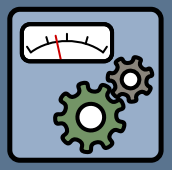

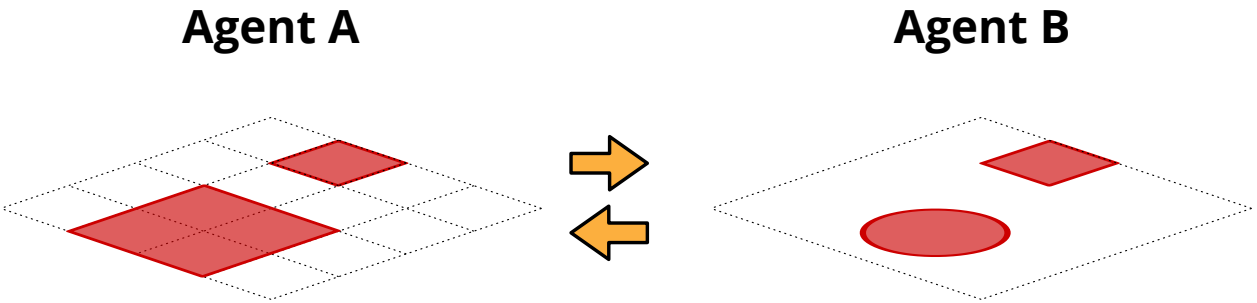

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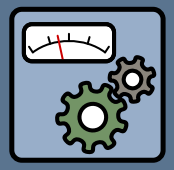
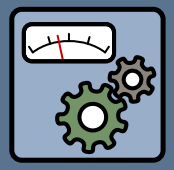
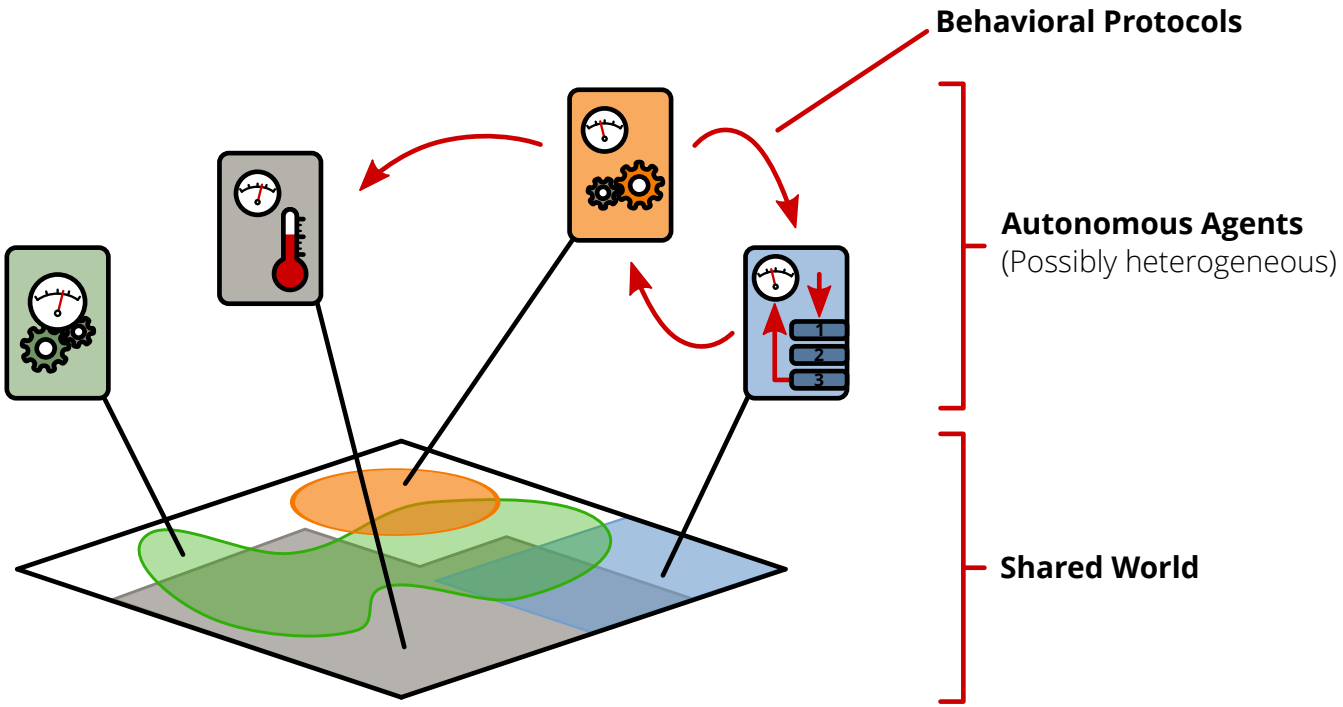


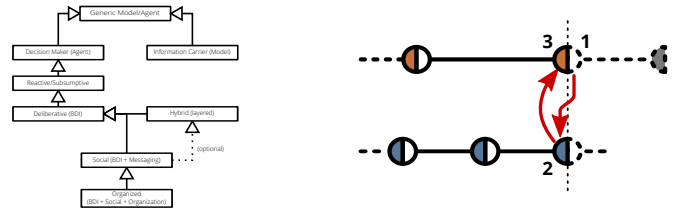
Outline



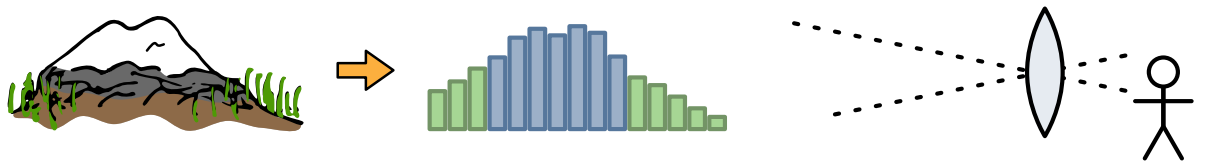
Problem Statement



Typical simulation arrangement: Software agents share a virtual world



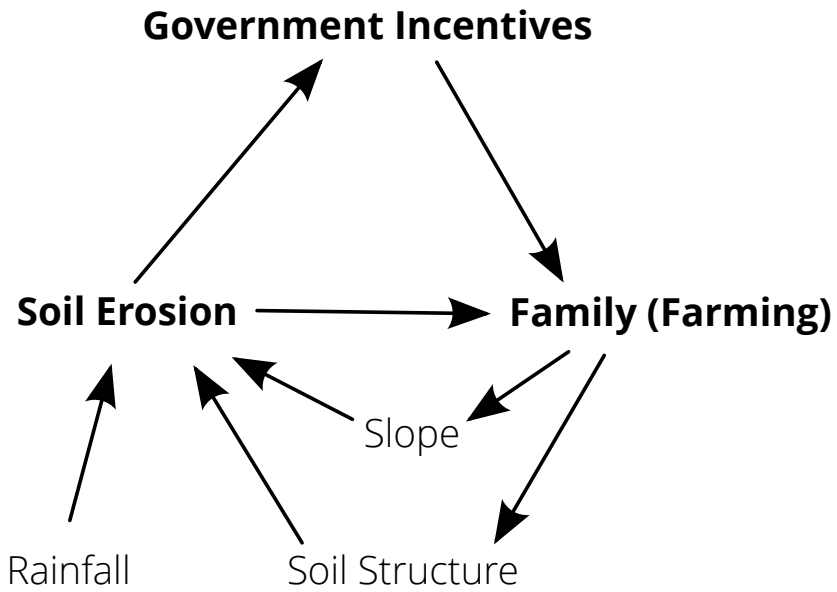
Semantics



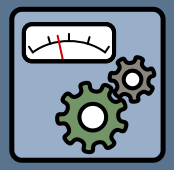
Scale Mediation

Perception

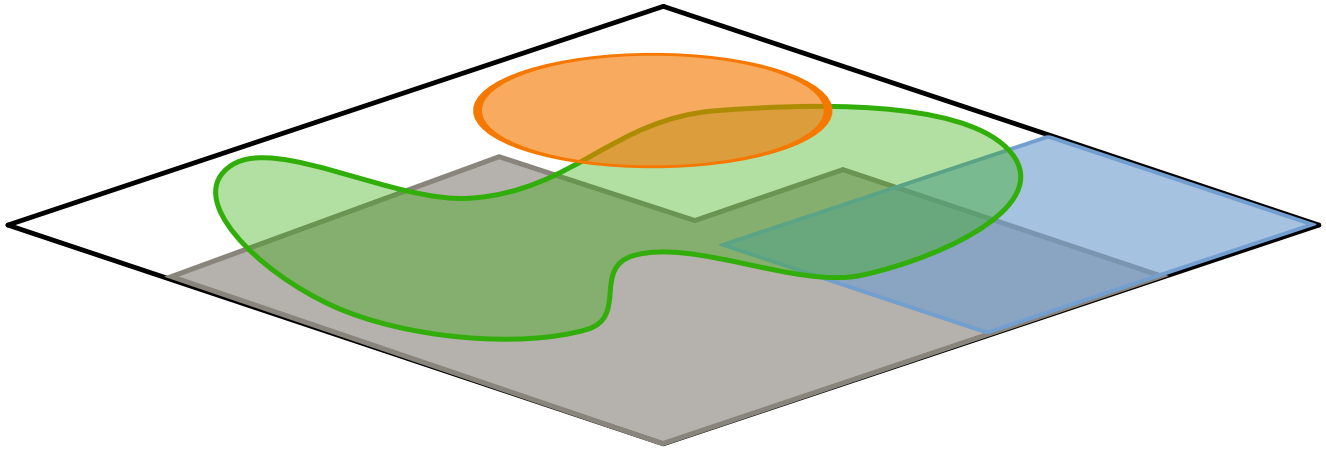
Sub-Problems

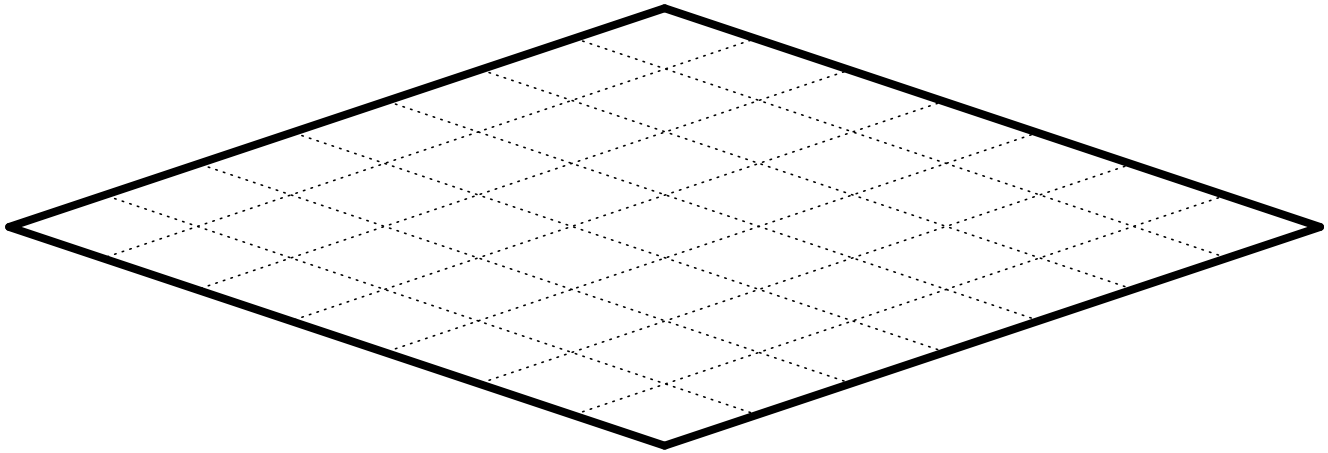


Typical Applications: Socioeconomic/geostatistical/ecosystem modeling

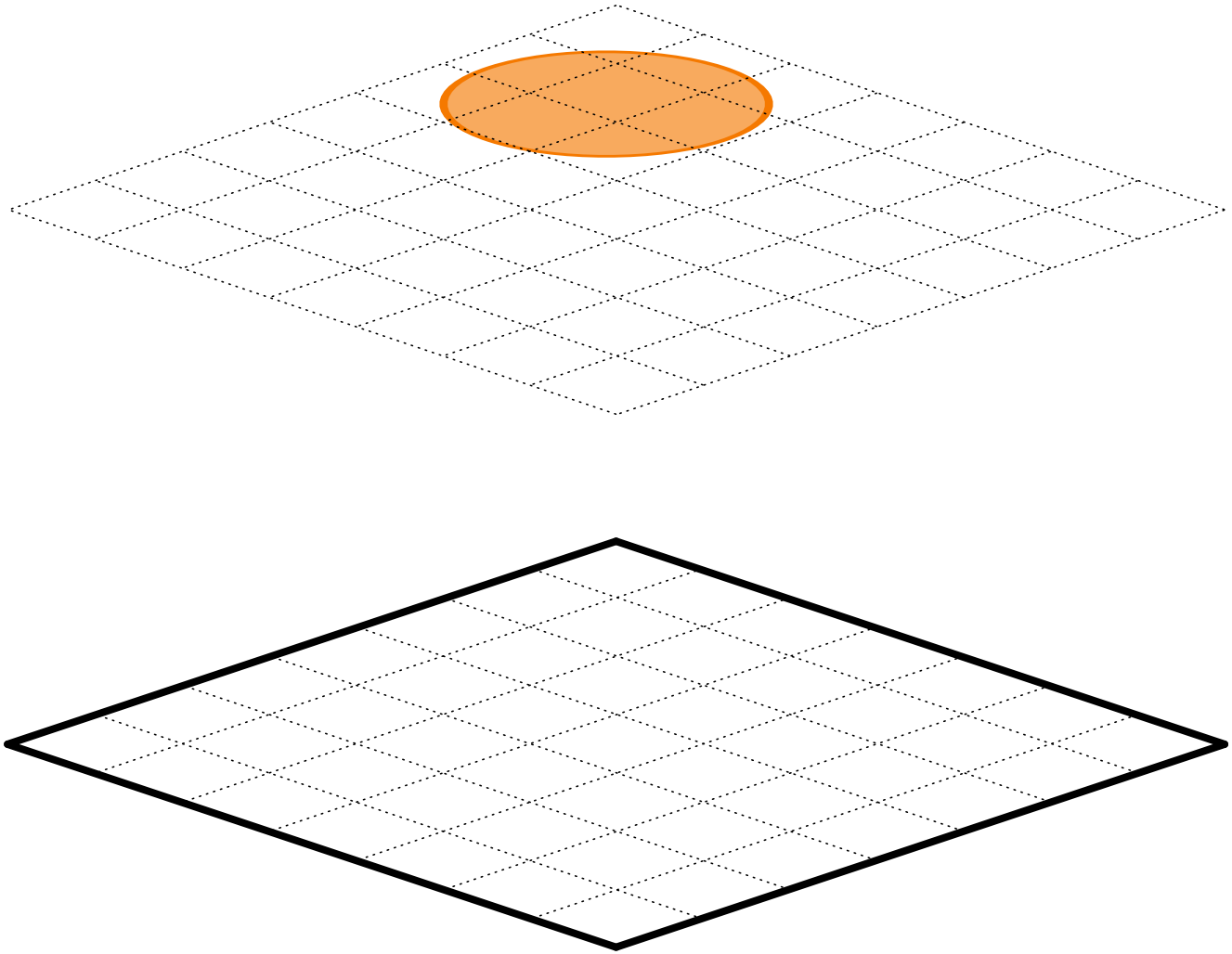


Common Technique: Cellular Space/Time

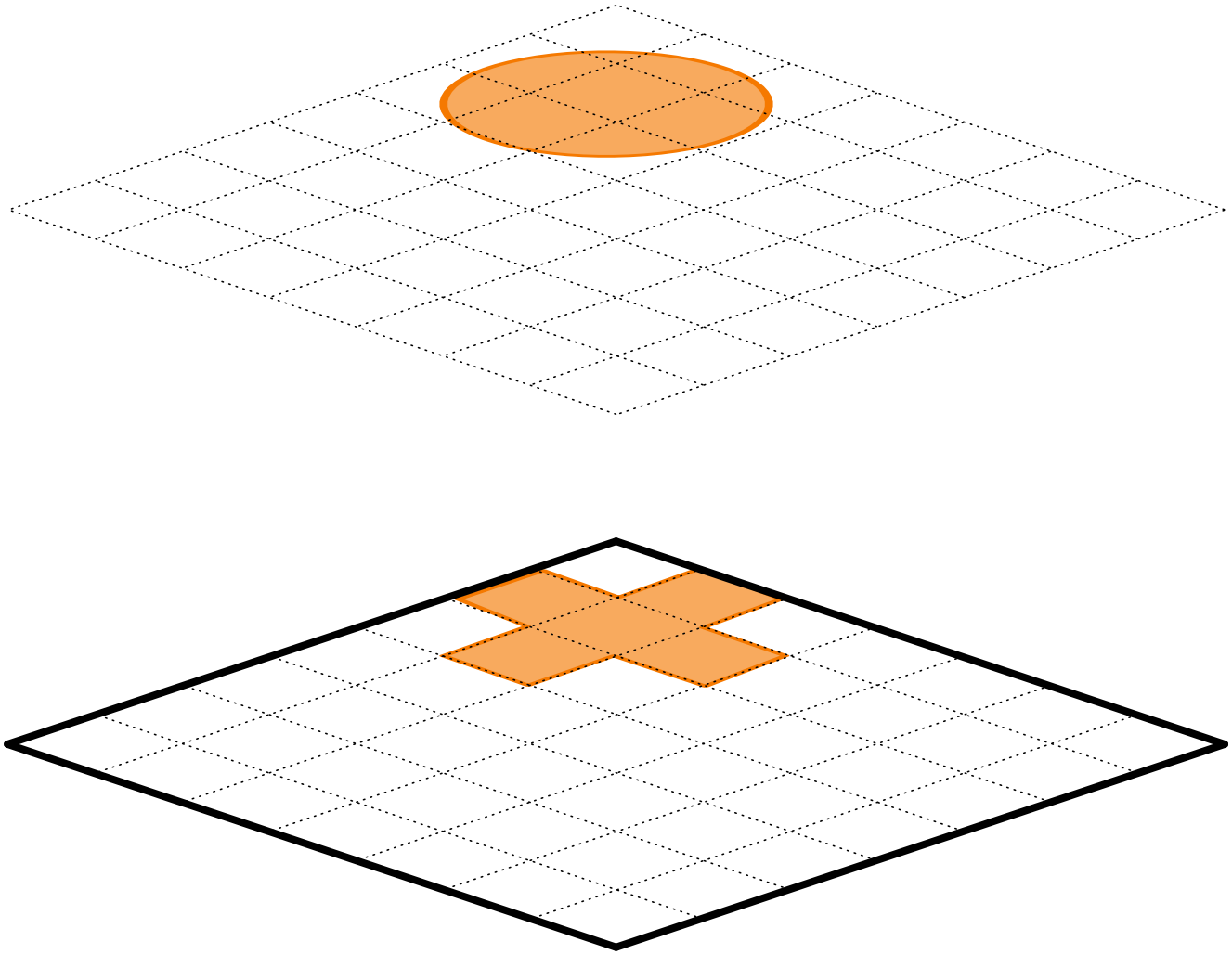




Shortcoming: Worlds are usually implemented as grids



Implication: Agents/models are modified



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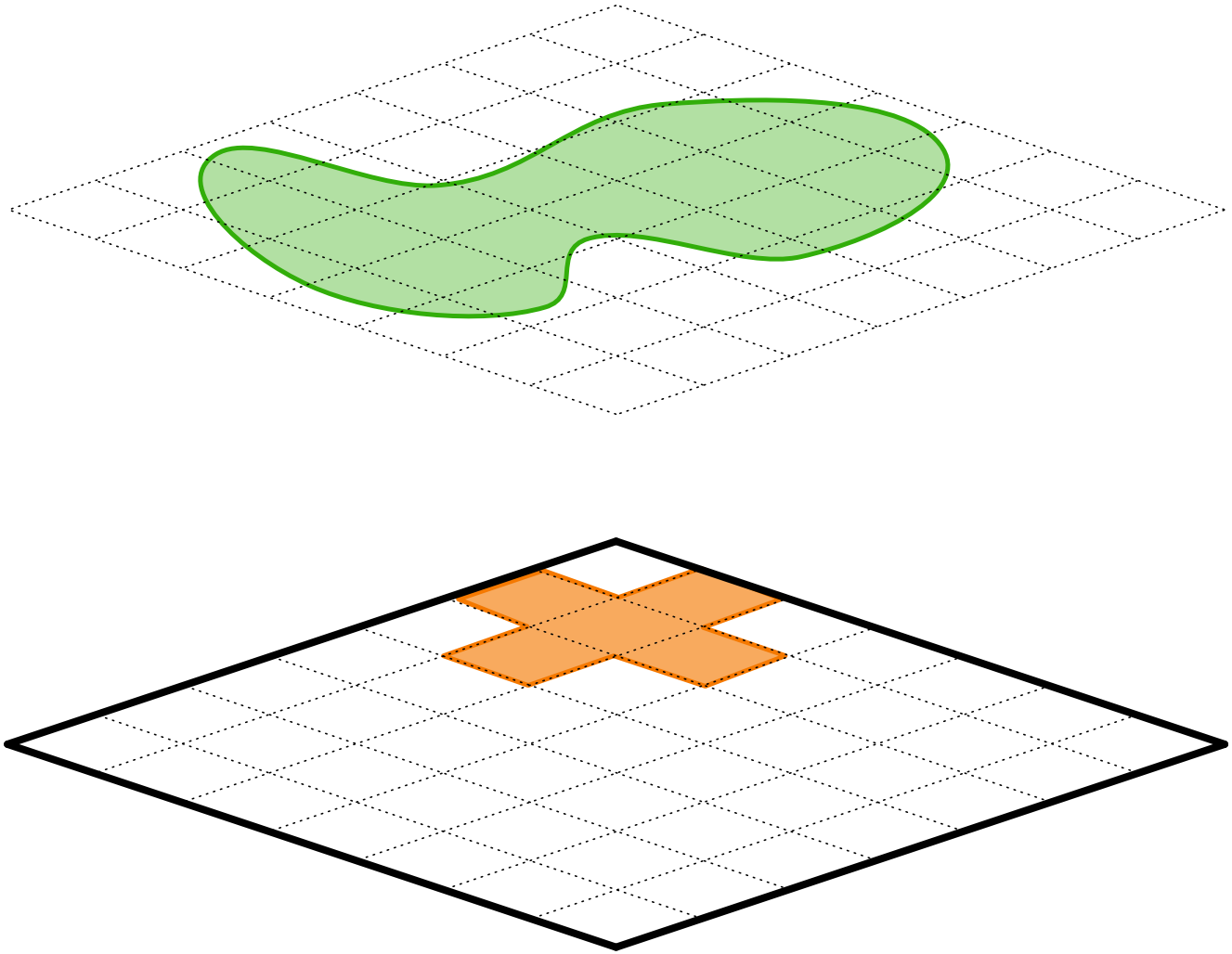

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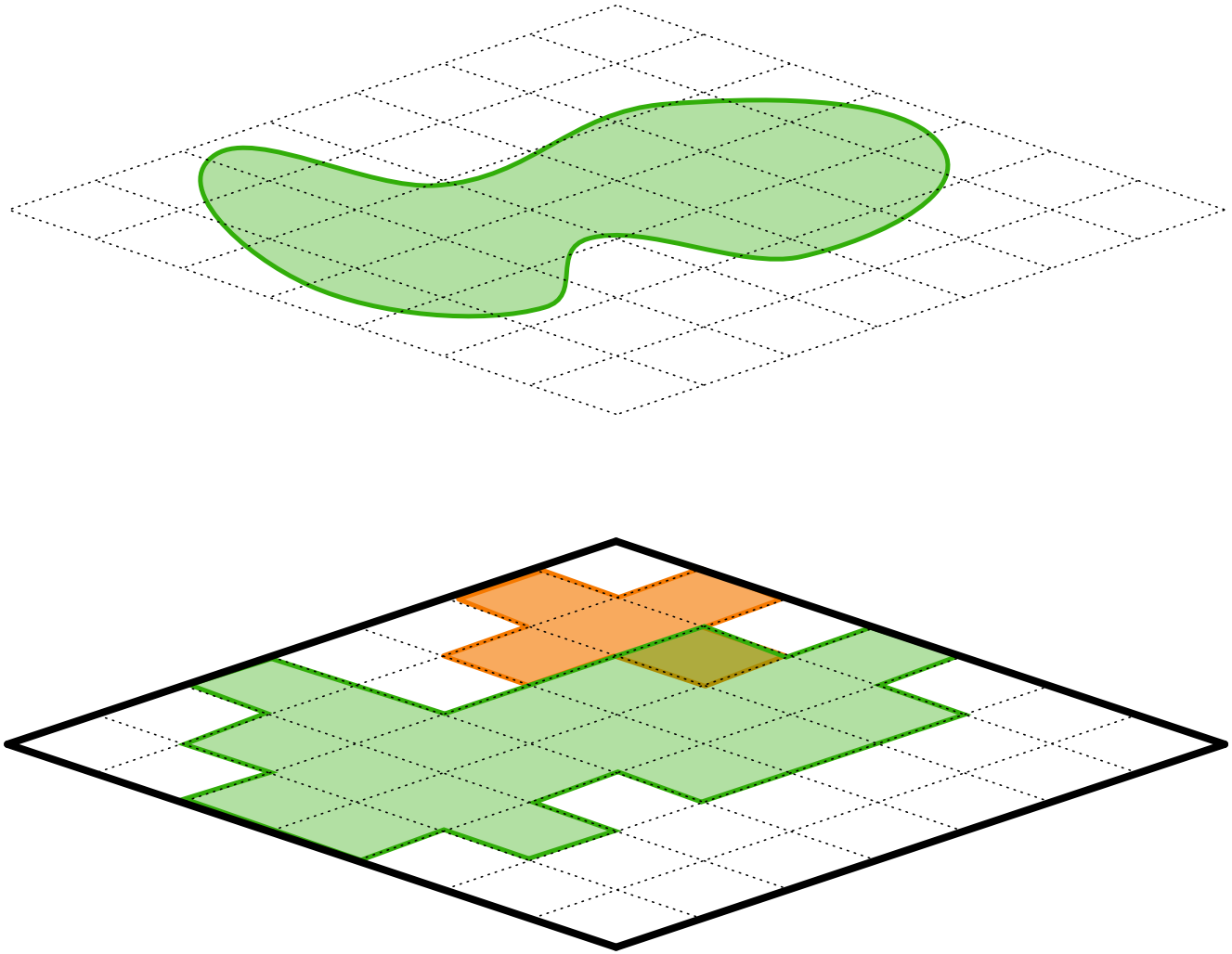

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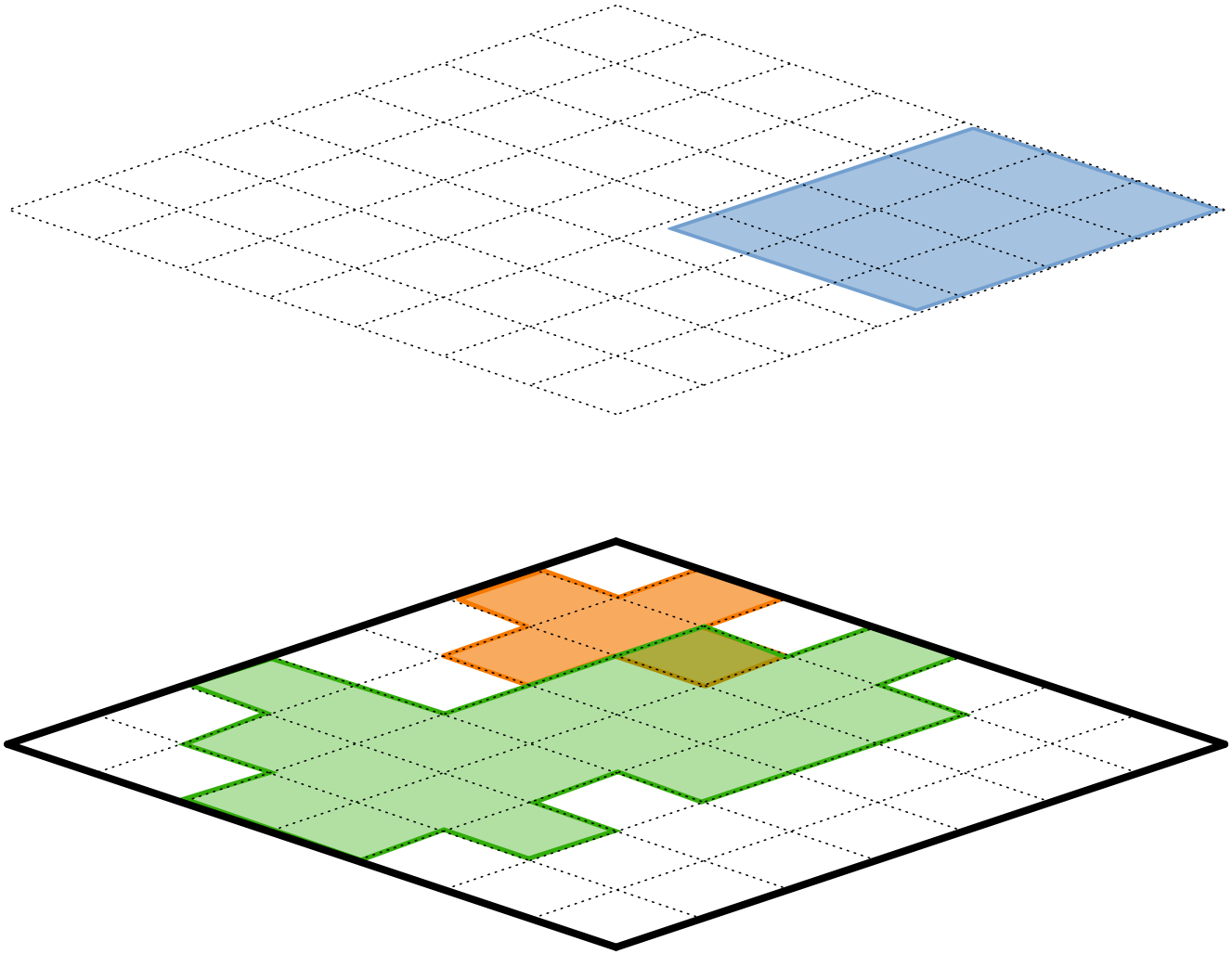

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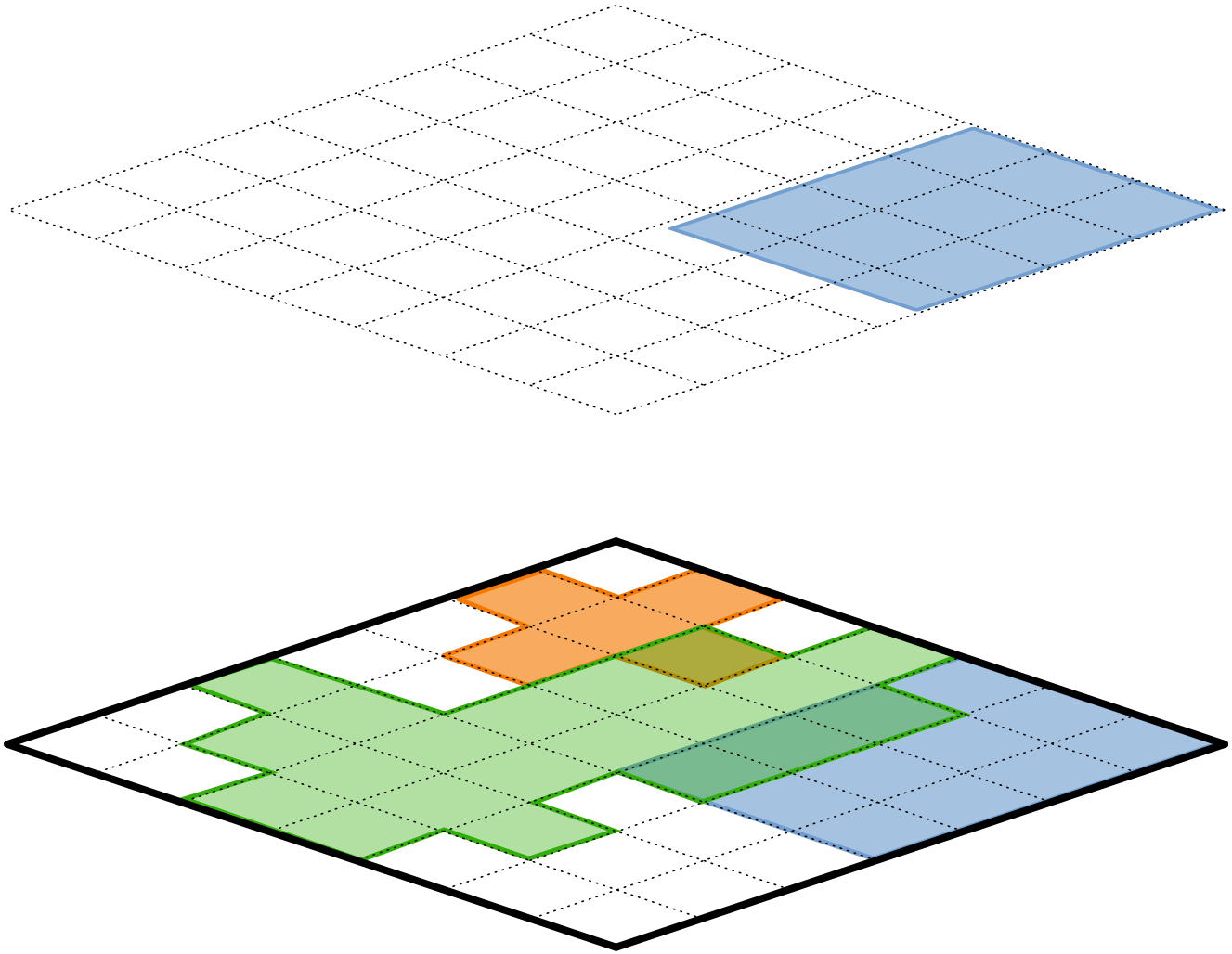

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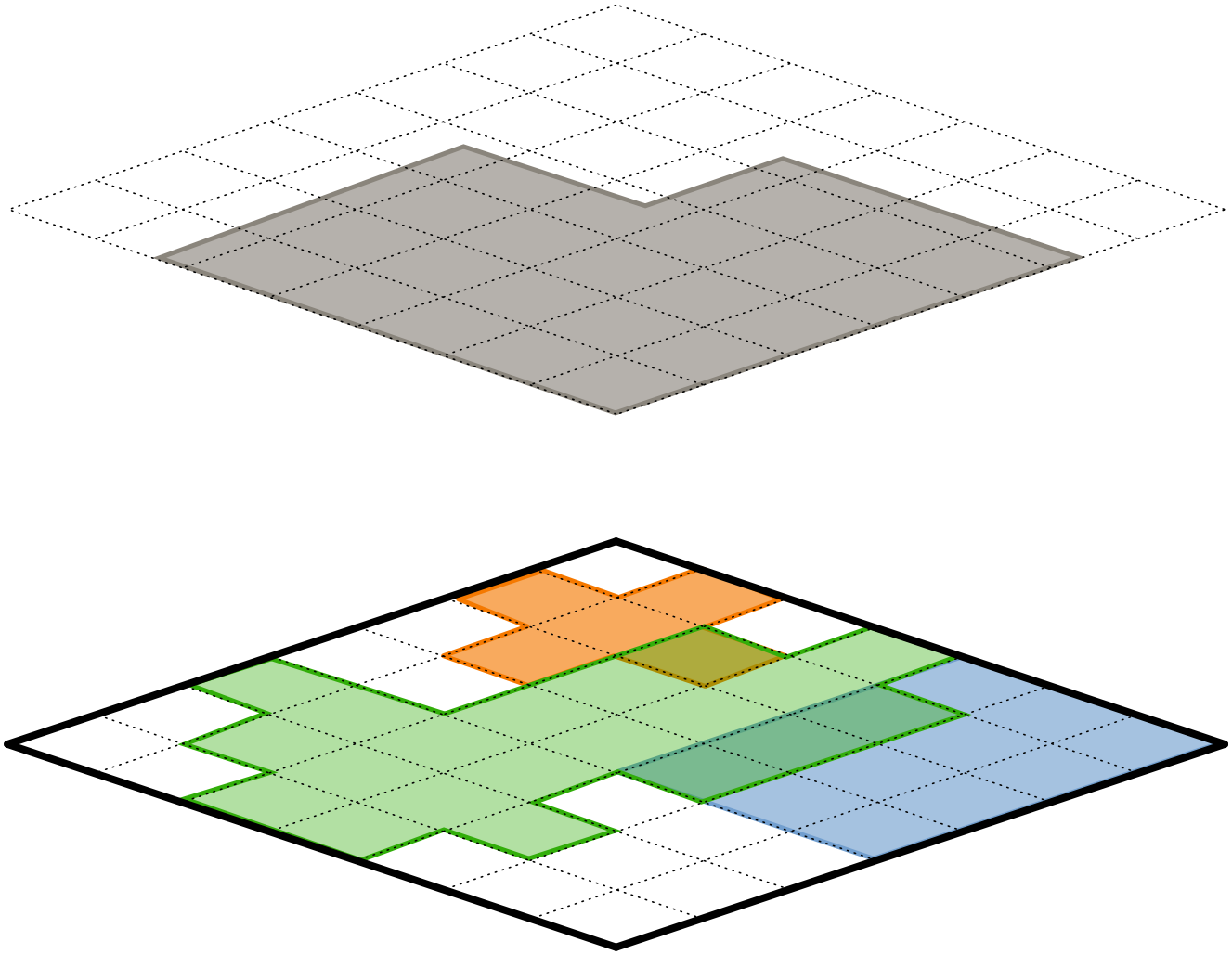

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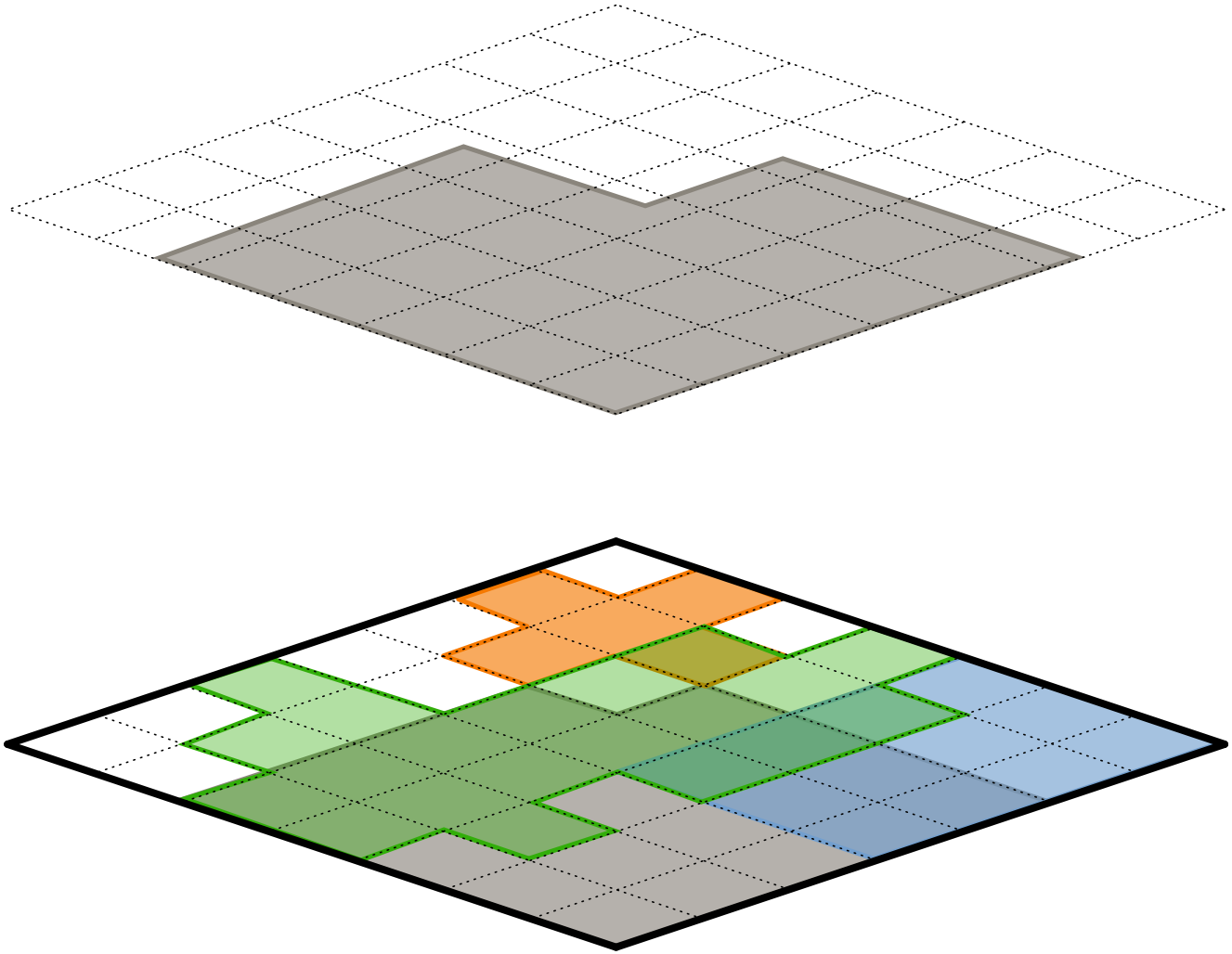

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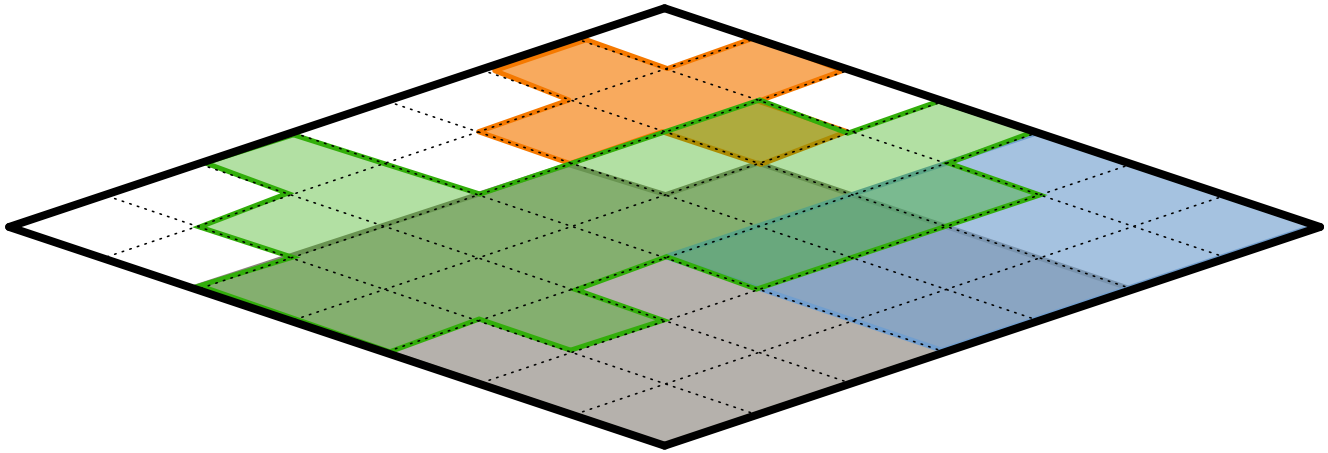

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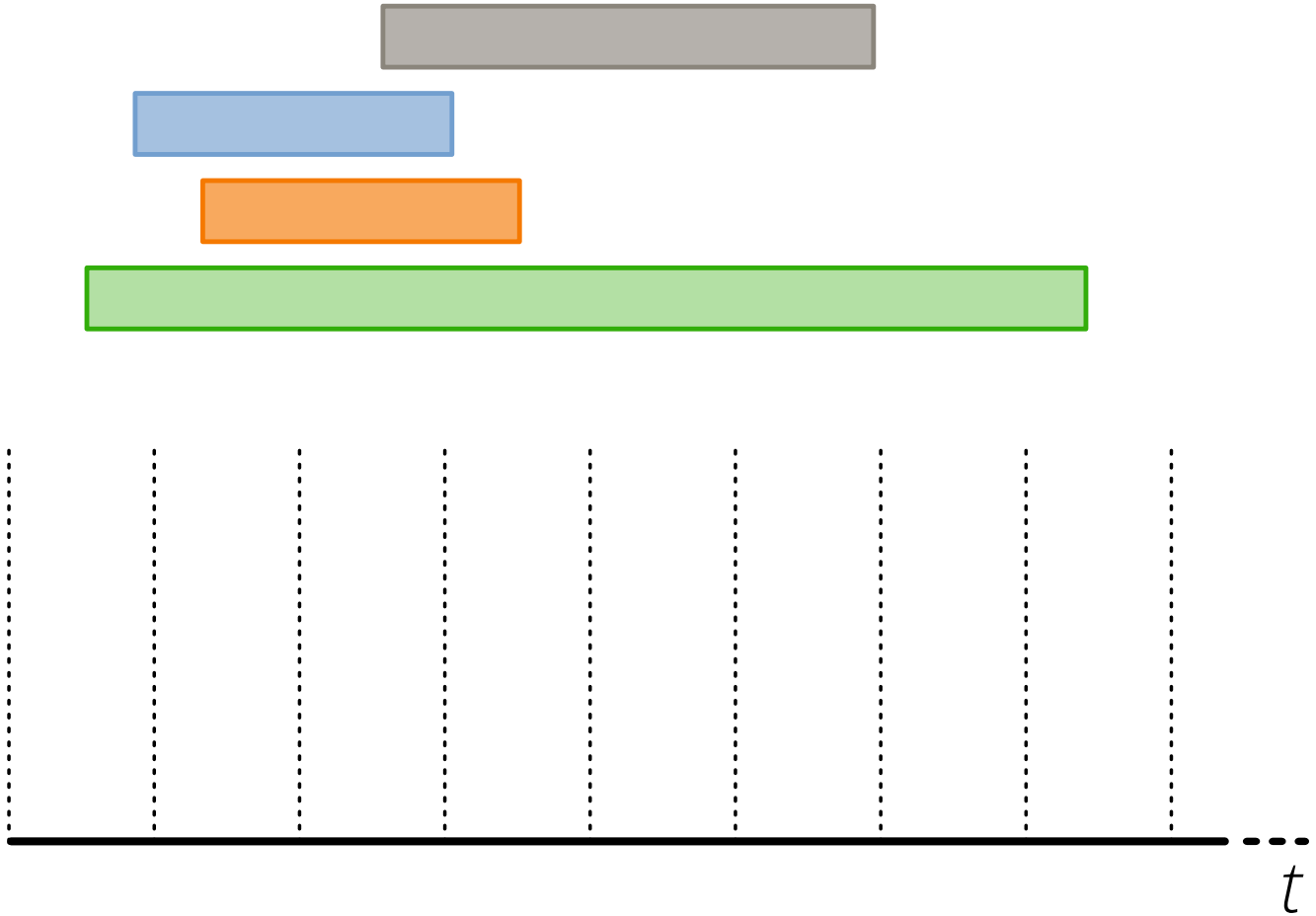
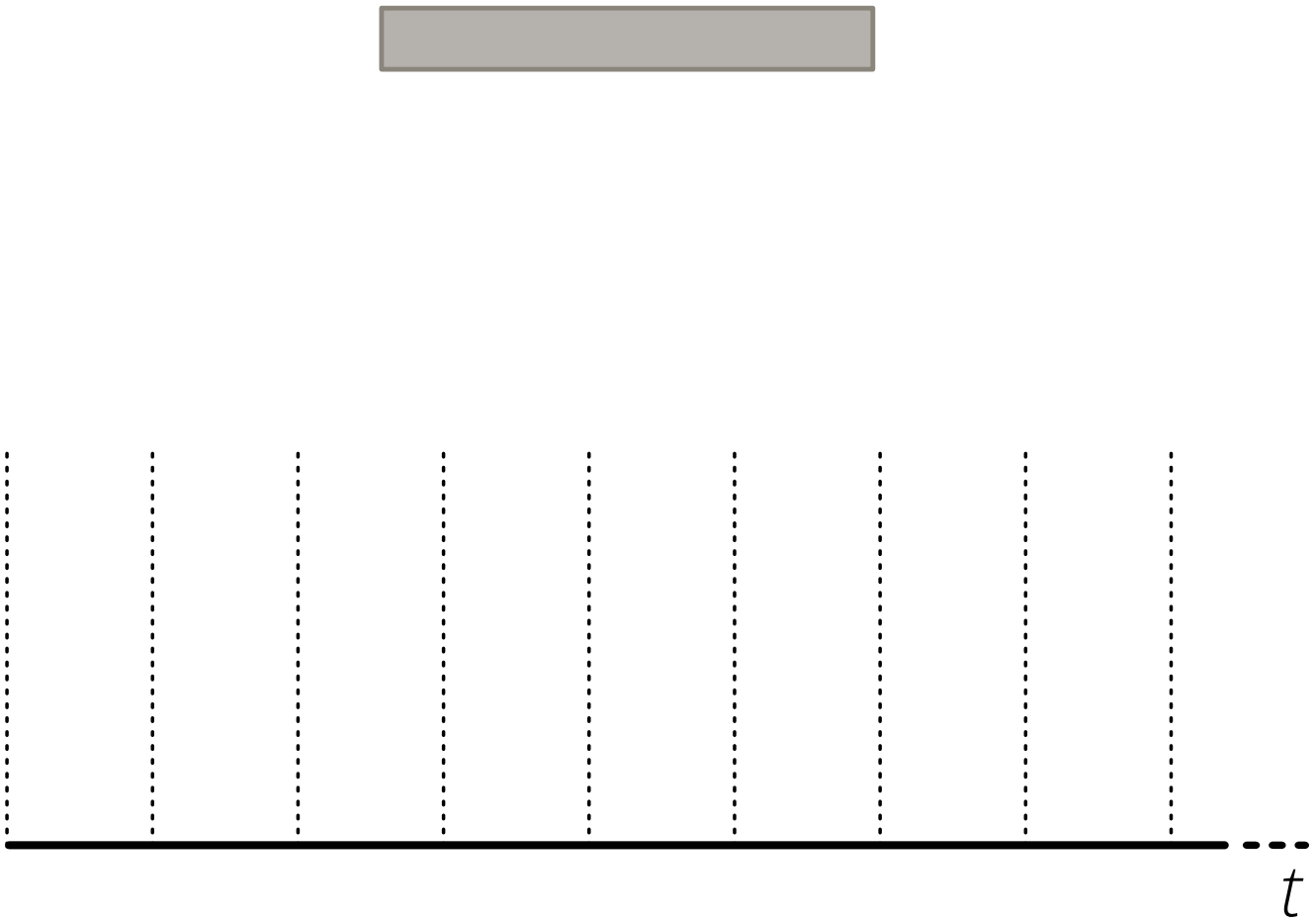


Temporal Scales: Similar implications to spatial dimensions



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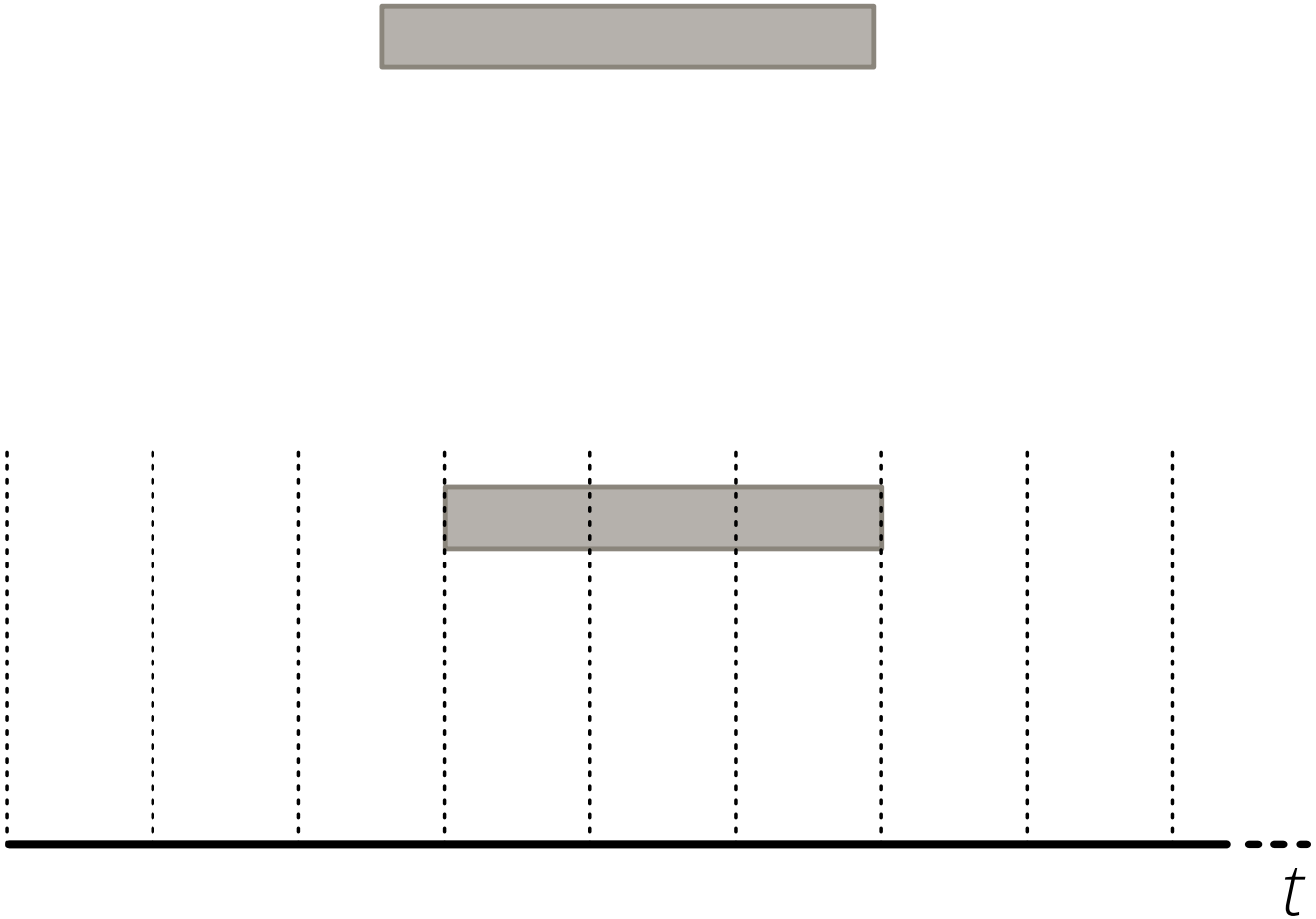

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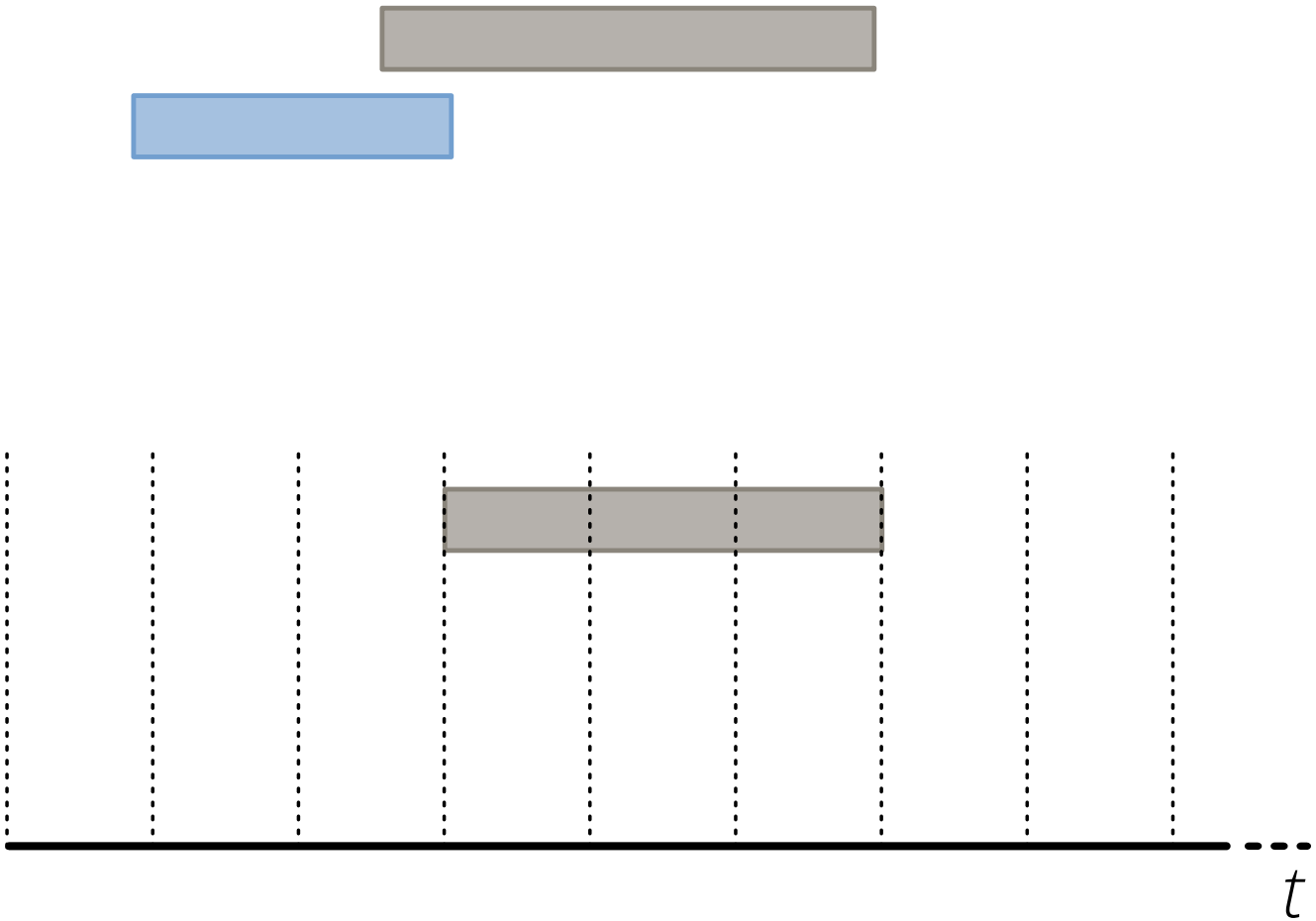

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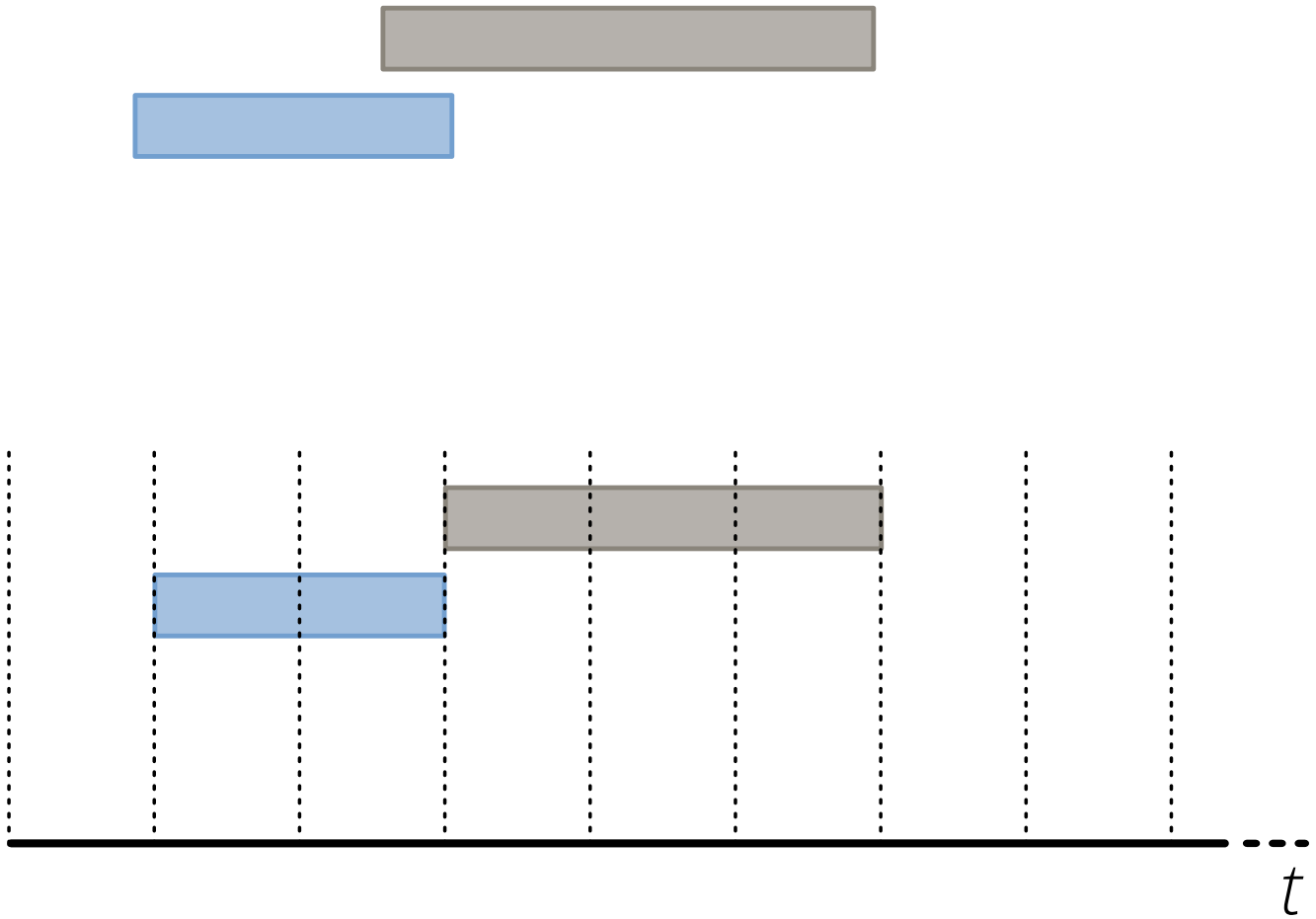

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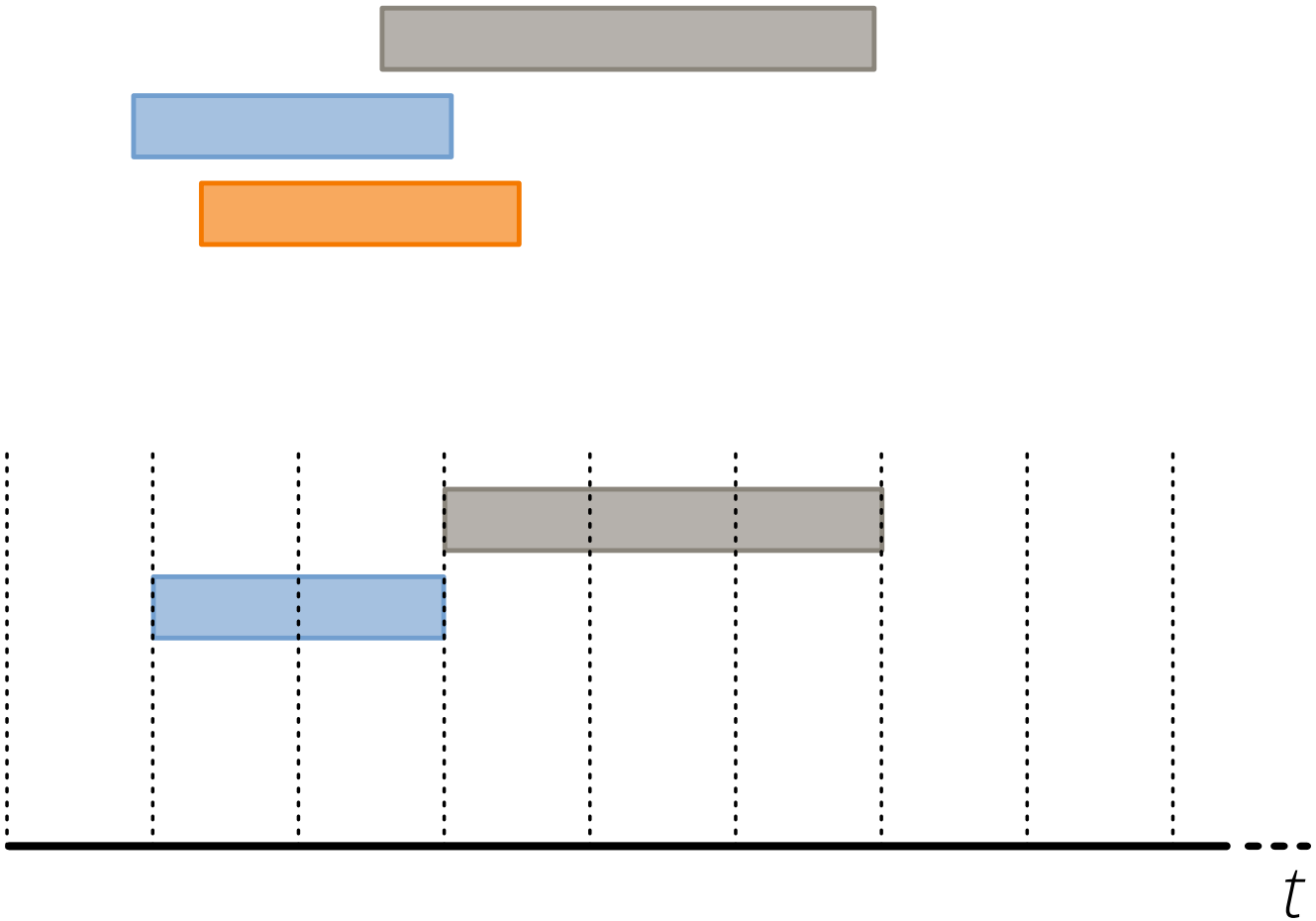

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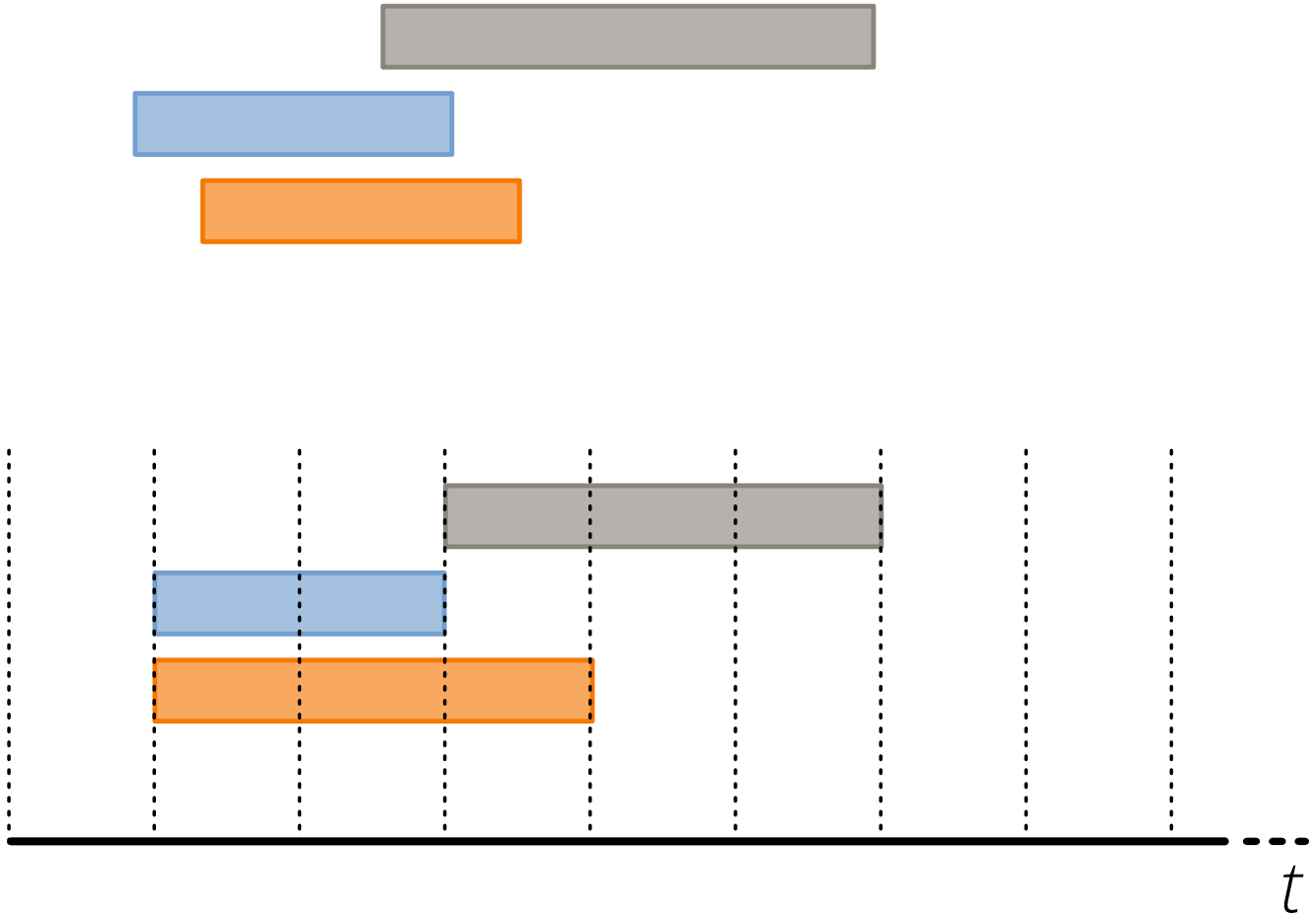

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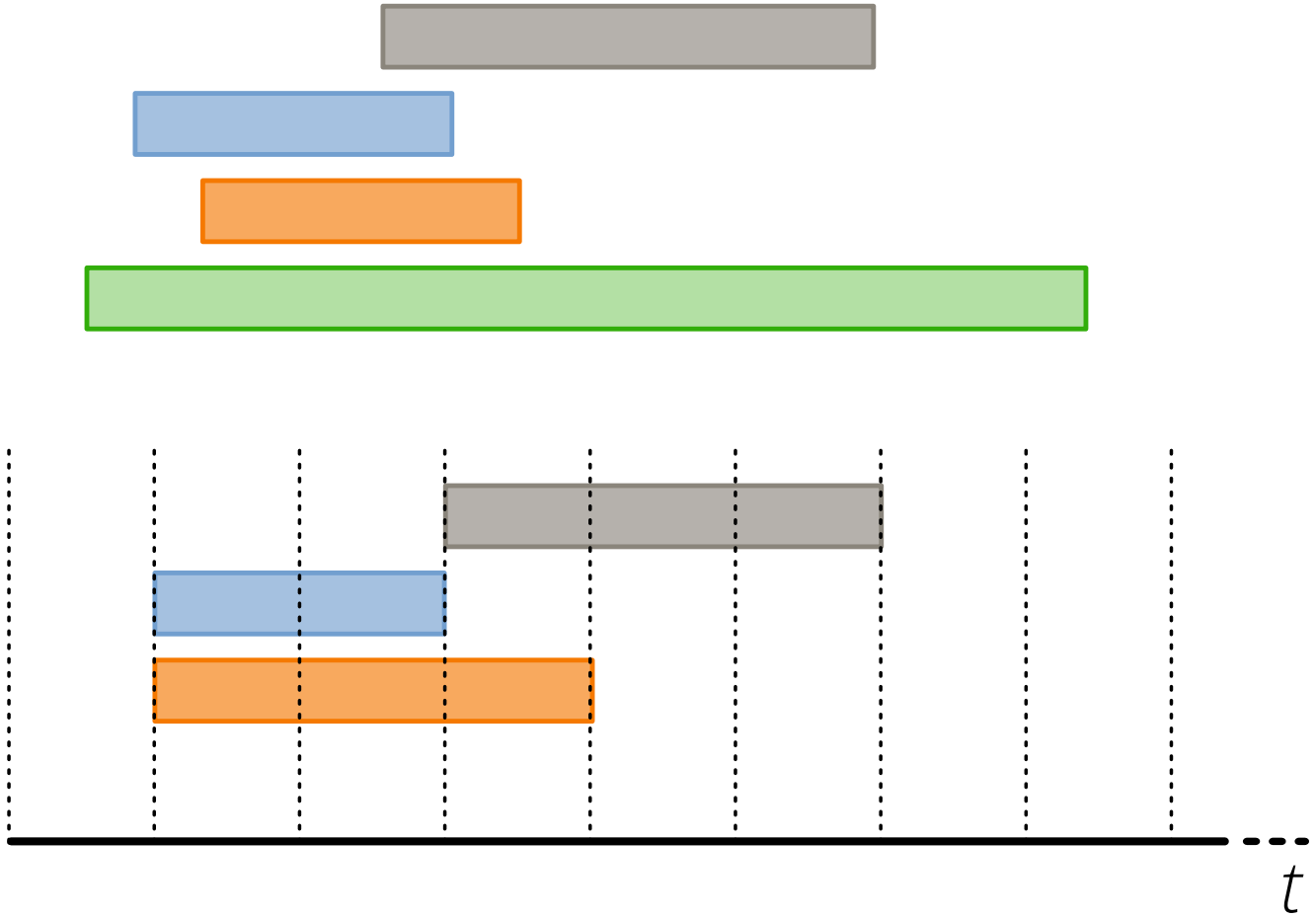

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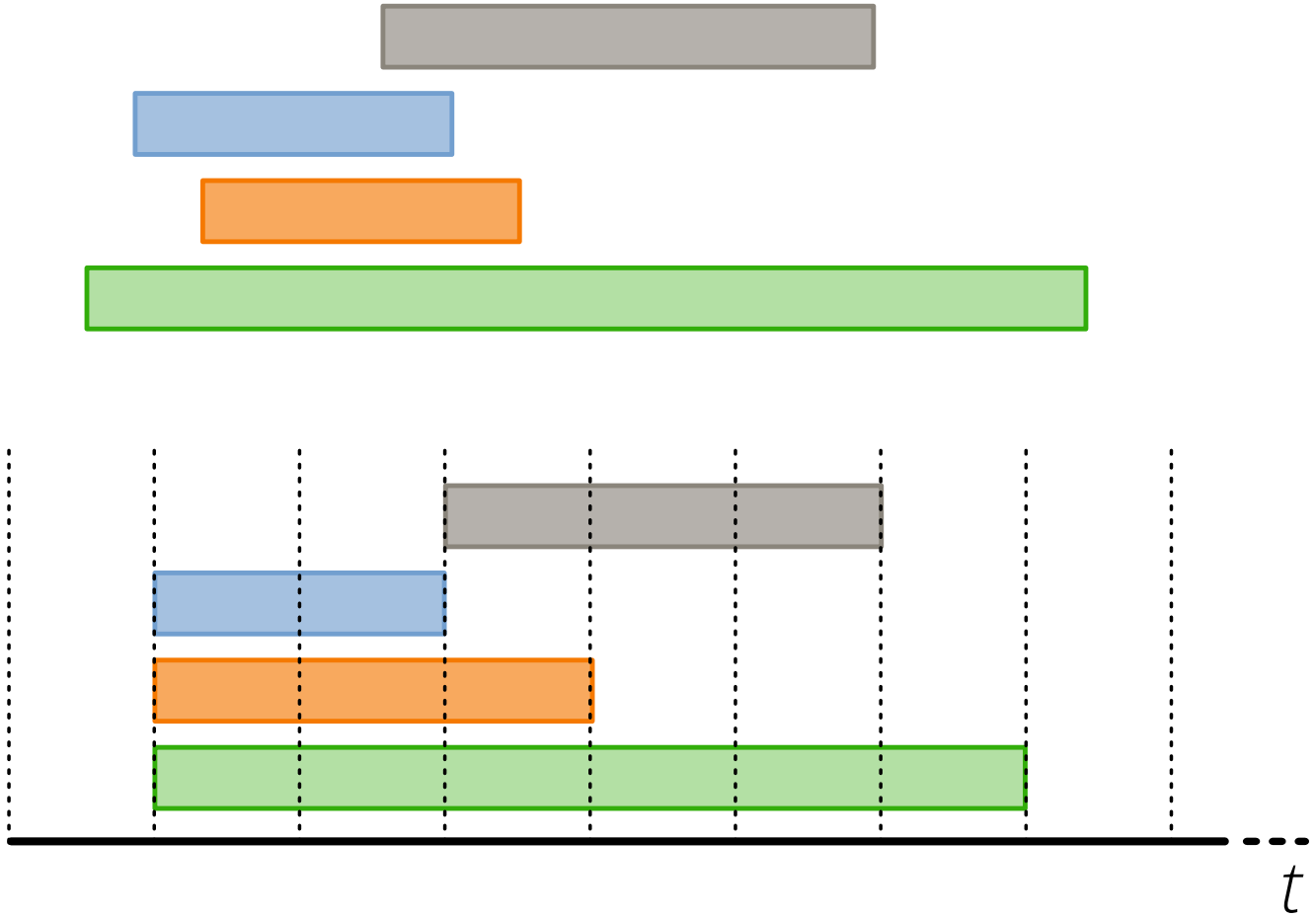

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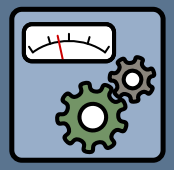
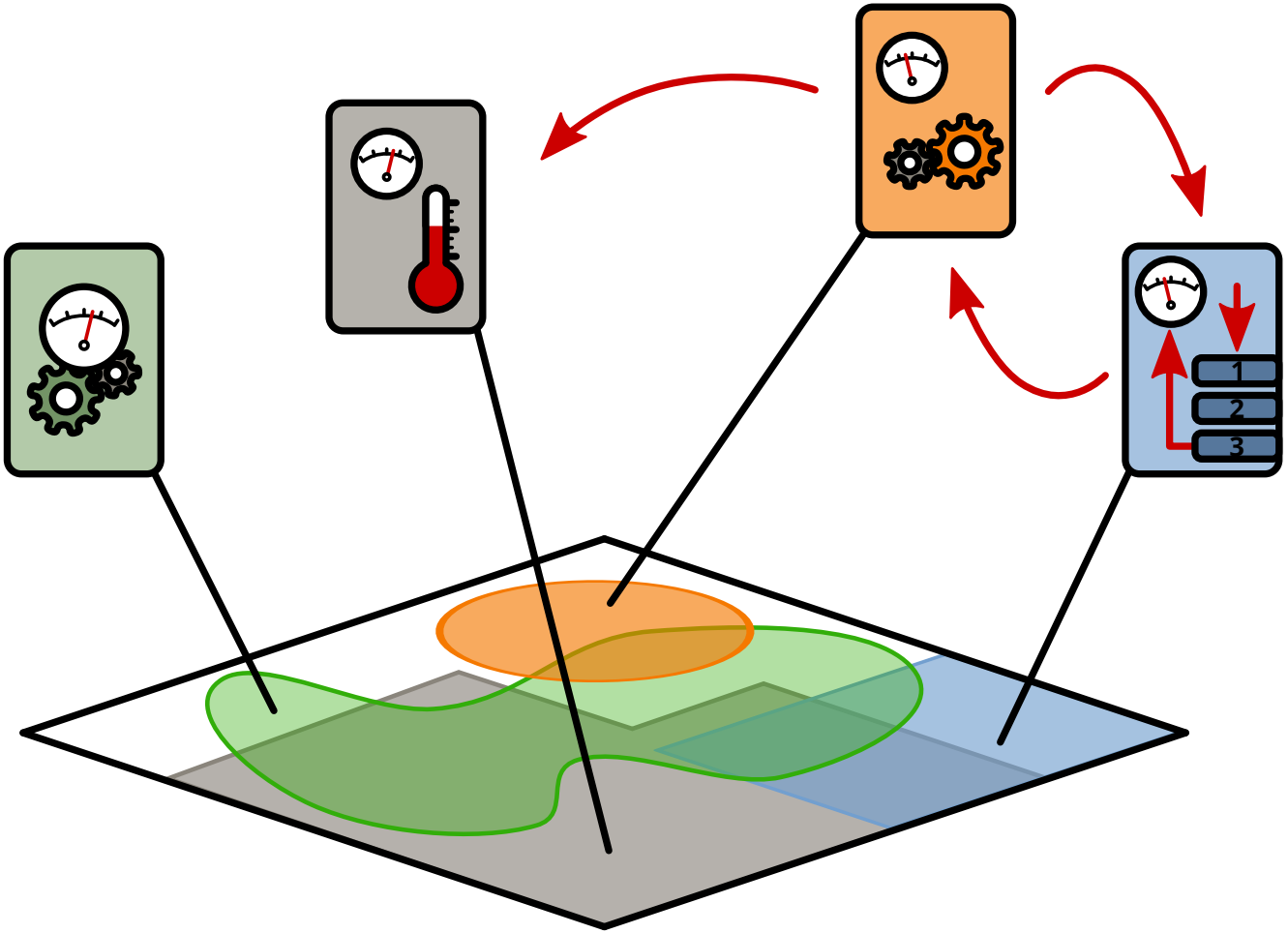
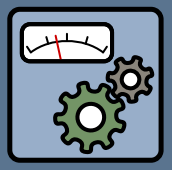
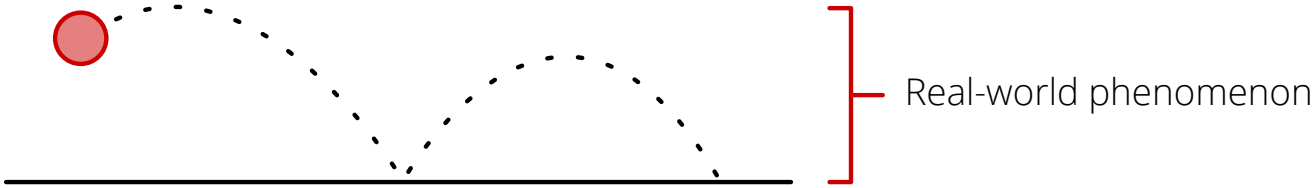


Related Academic Fields

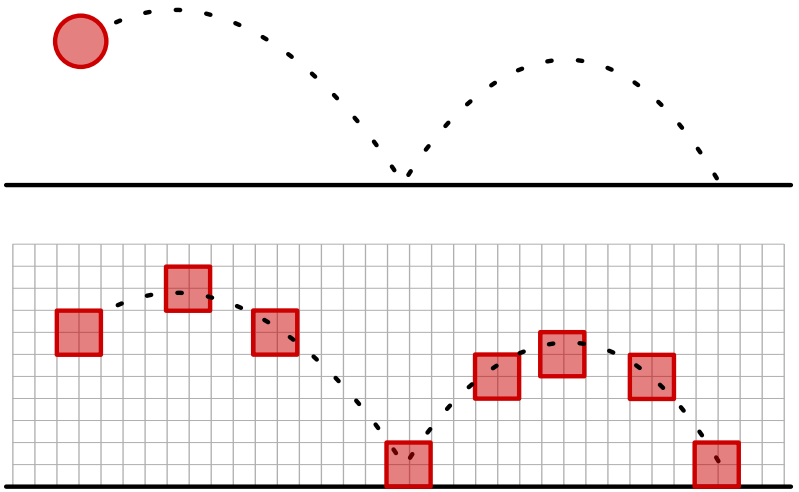


Related Field: Agent Modeling



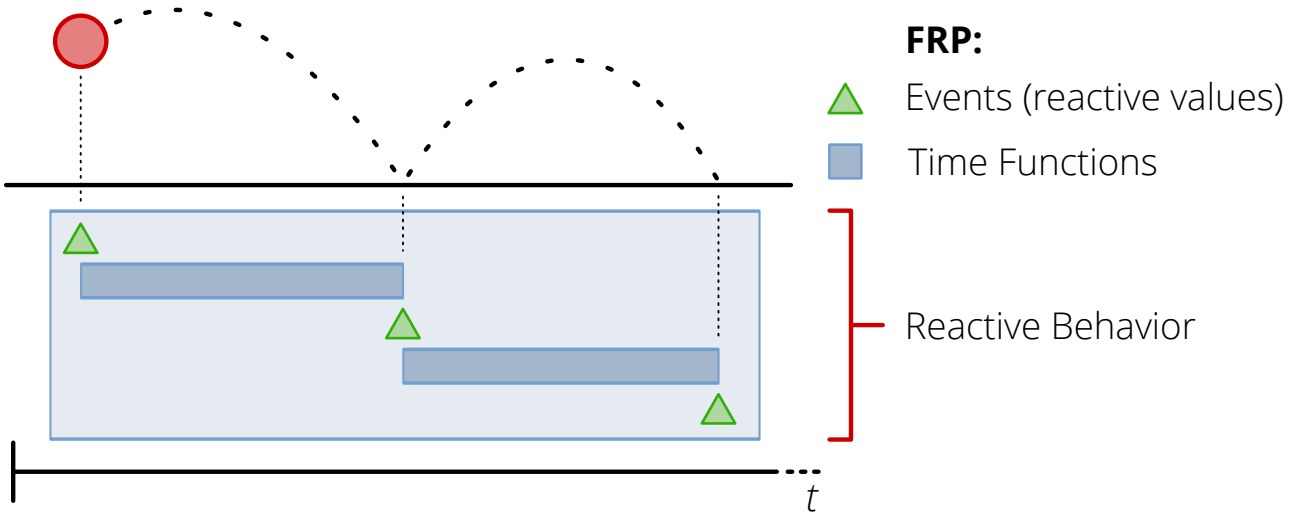


Related Field: Functional Reactive Programming [1, 2]



Discretization:
Pixel- and frame-based animation

Related Field: Functional Reactive Programming [1, 2]



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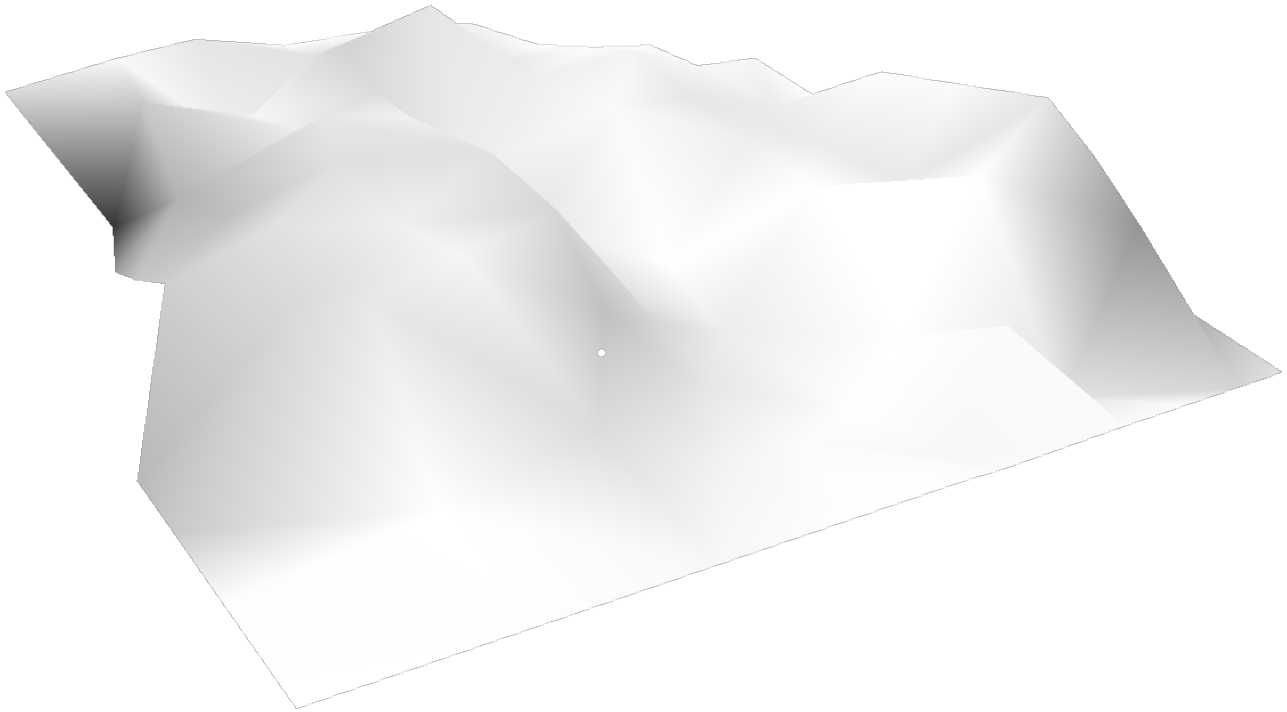
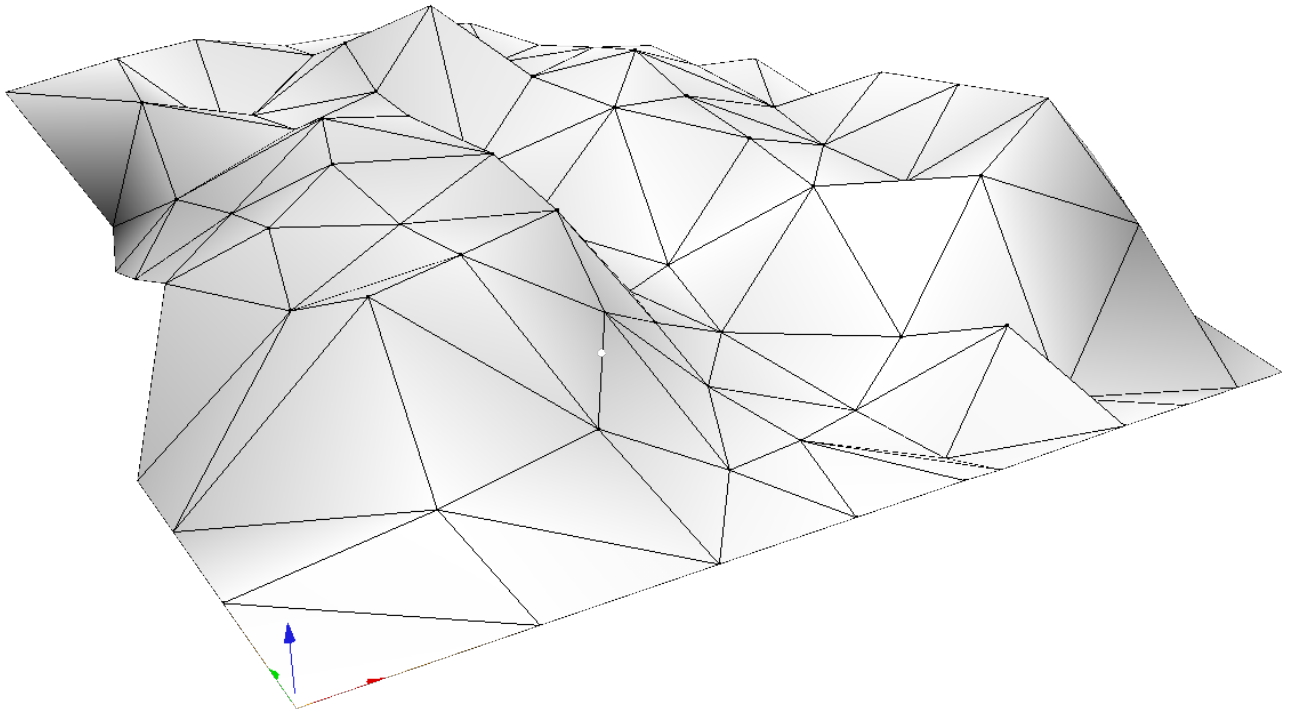


Related Field: Geospatial Interpolation [3]



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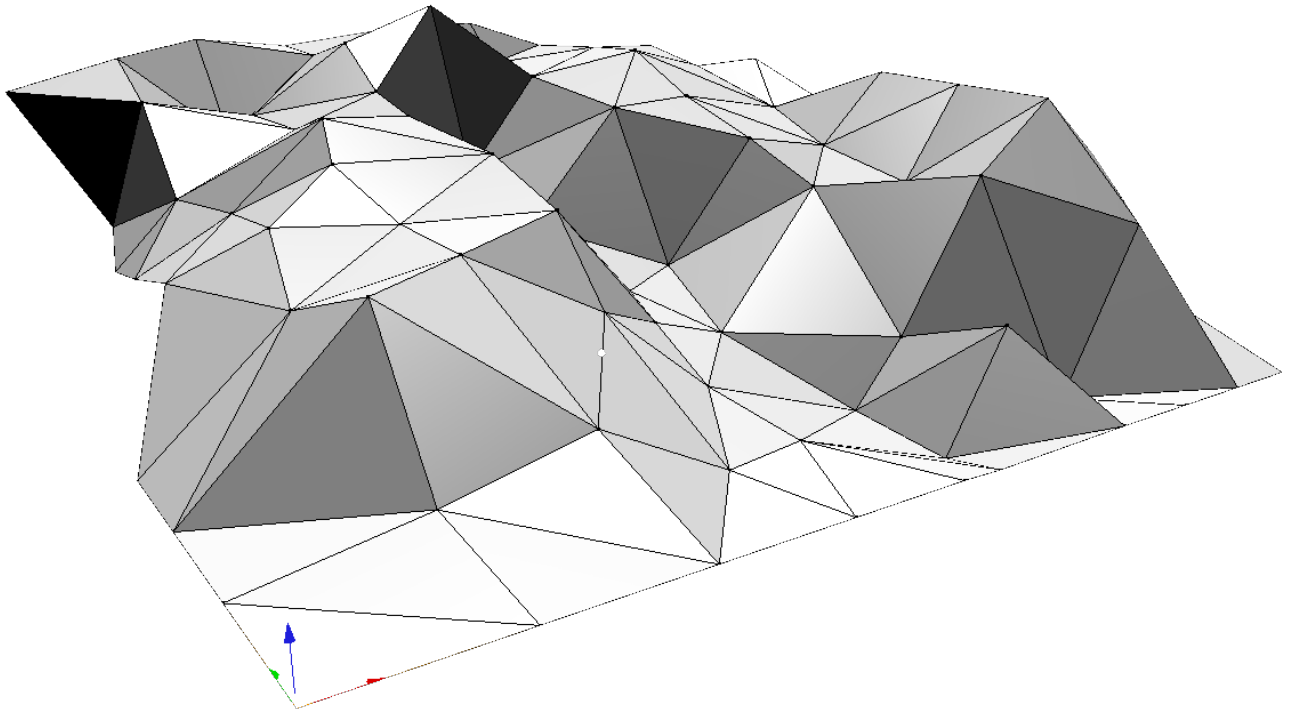

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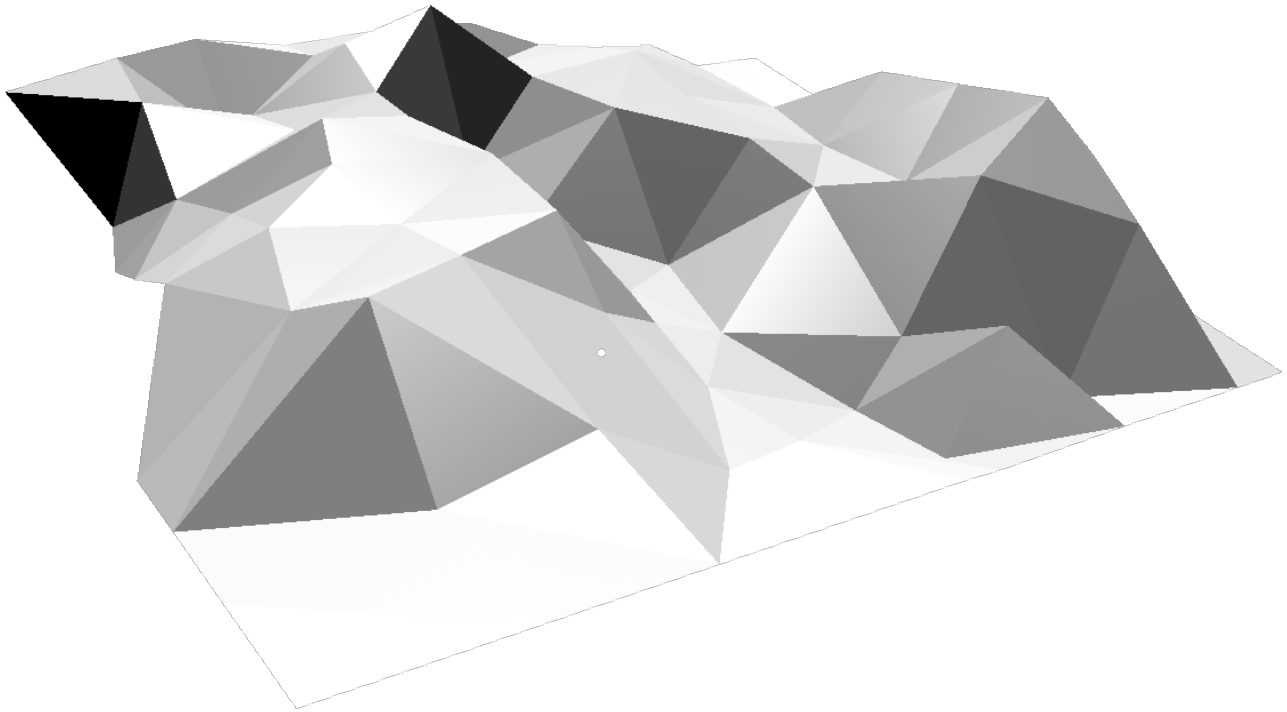

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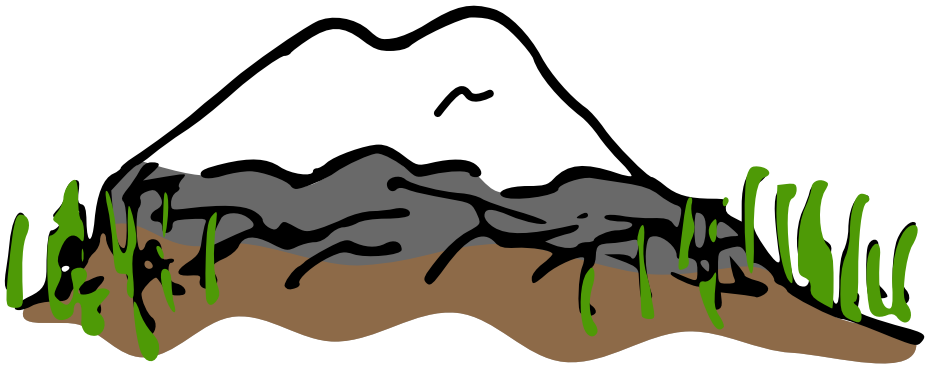


Original Image
(before discretization)

Related Field: Image Interpolation

Discretized:
75x30 pixels

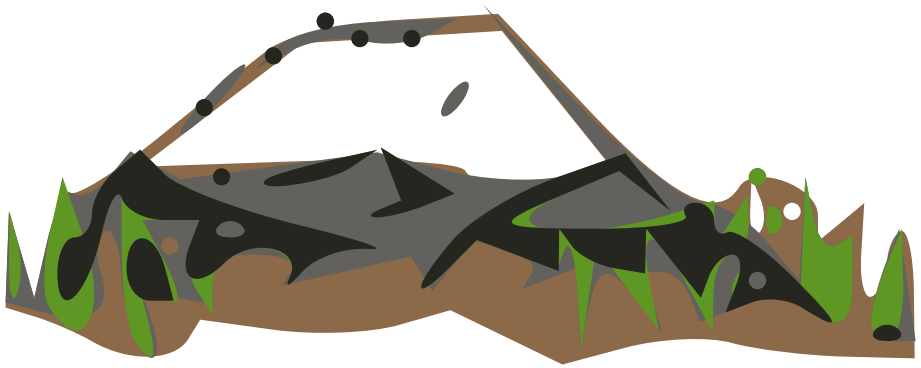
Related Field: Image Interpolation

Interpolation:
Linear

Related Field: Image Interpolation

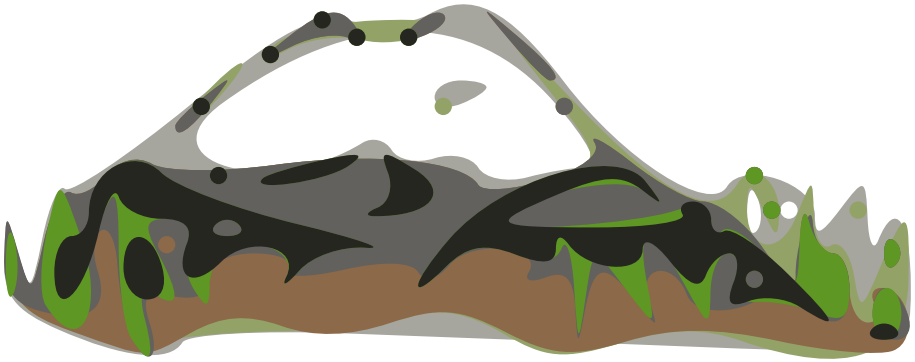
Interpolation:
Cubic

Related Field: Image Interpolation



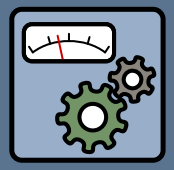
Vectorized:
Moderate smoothing,
fewer colors

Related Field: Image Interpolation



Vectorized:
Aggressive smoothing, more colors

Related Field: Image Interpolation

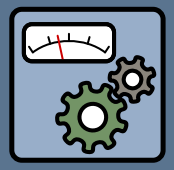


Further Reading (other related fields):

Signal Interpolation

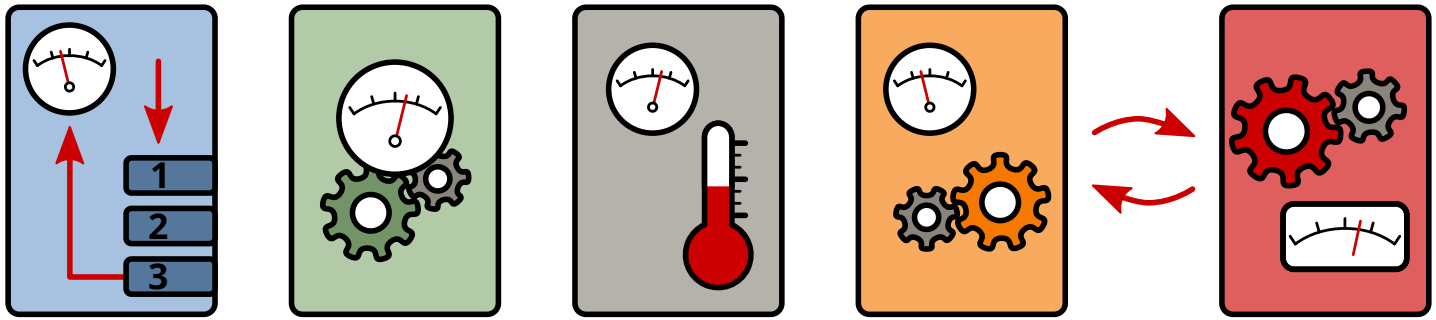
Signal Theory

Collision Detection



Scale Mediation Theme:

Discretization vs. **Continuous Representation**



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- **Standard** across dimensions, agents, ontological concepts, etc.
- **Accessible**, intuitive scale concepts
- **Flexible** customization
- **Easy** for modelers/developers

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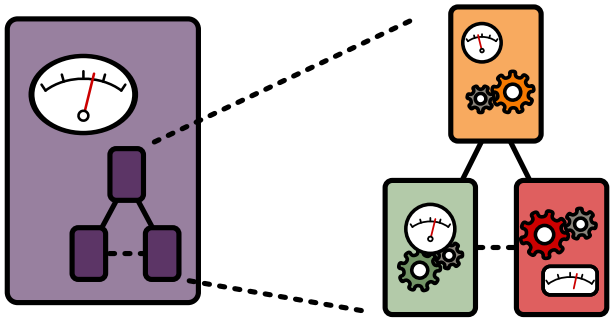

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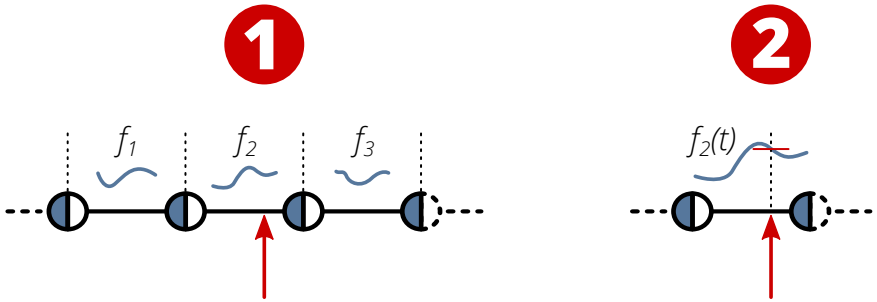

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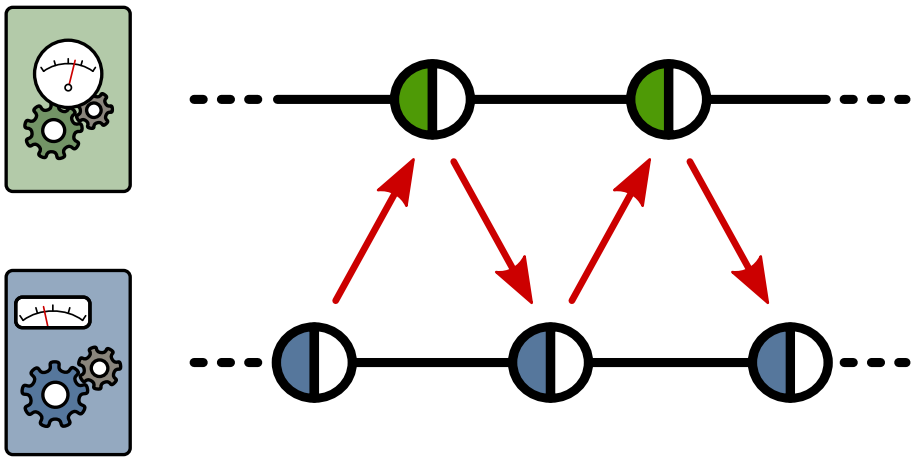
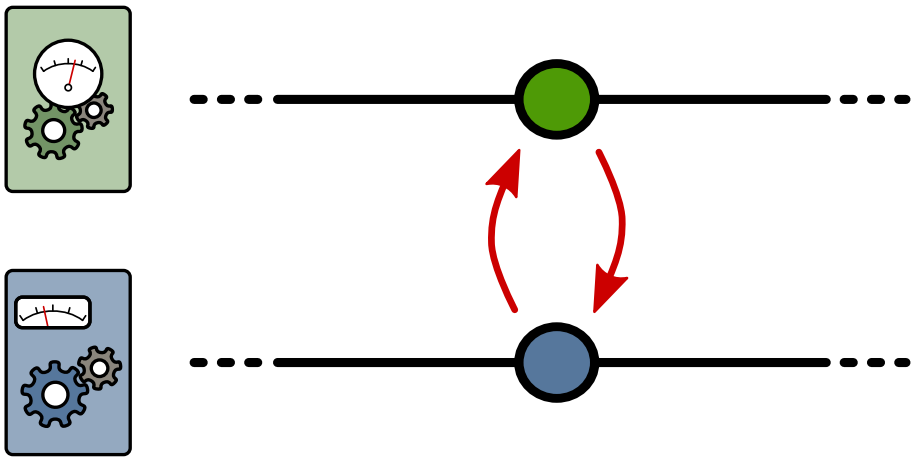


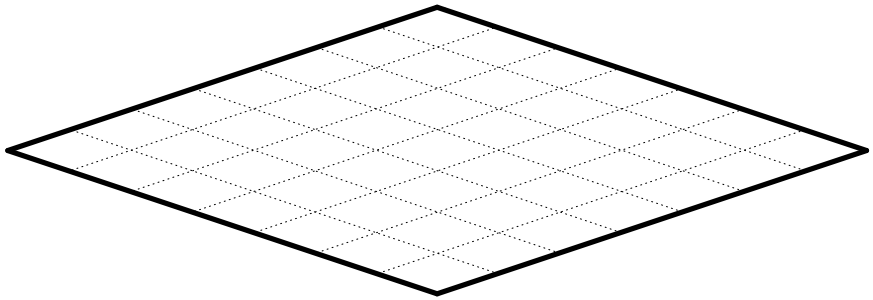
Cyclic Dependency:
Normal Part of the Real World

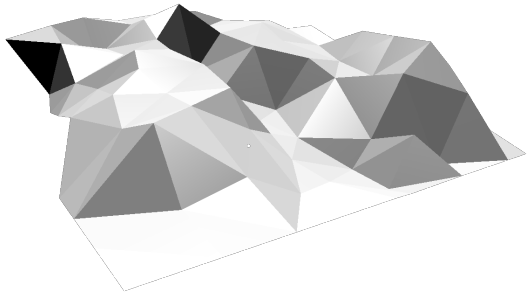
Circular Reference Handling



Circular Reference:
Artifact of Flawed Modeling

Circular Reference Handling





Differences in Scale (unbounded definition):

- Different **number of dimensions:** 2D vs. 3D space, temporal vs. atemporal models, etc.
- Different **concepts of domain:** Regular vs. irregular cells, microscopic vs. macroscopic sizes, etc.
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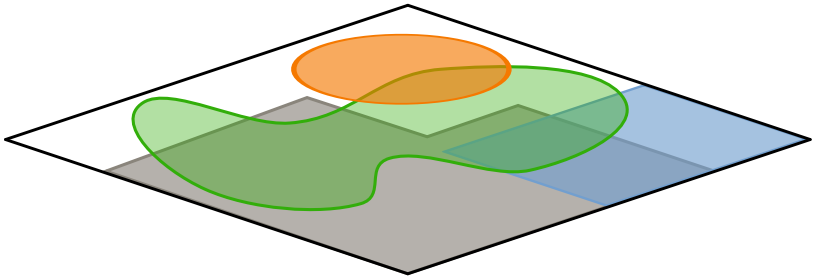

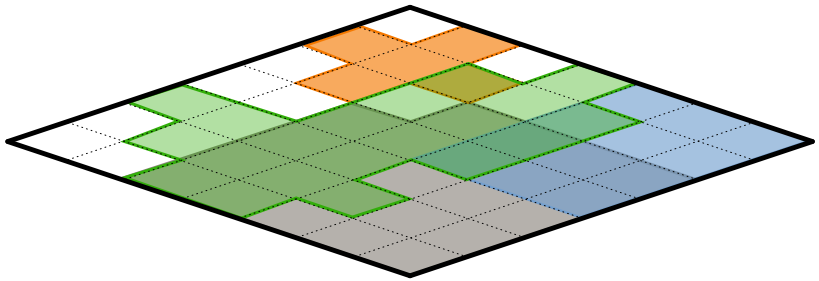

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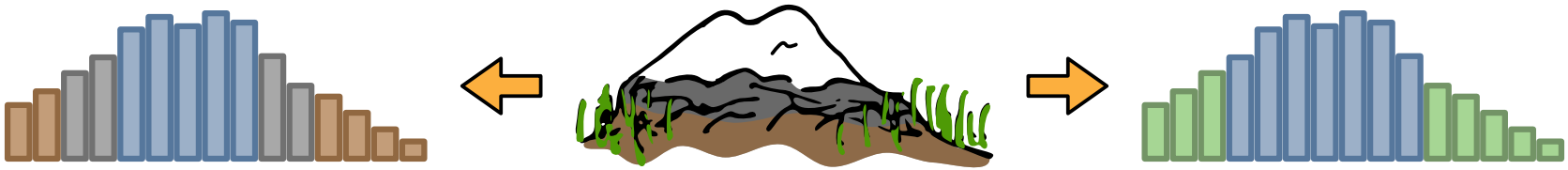

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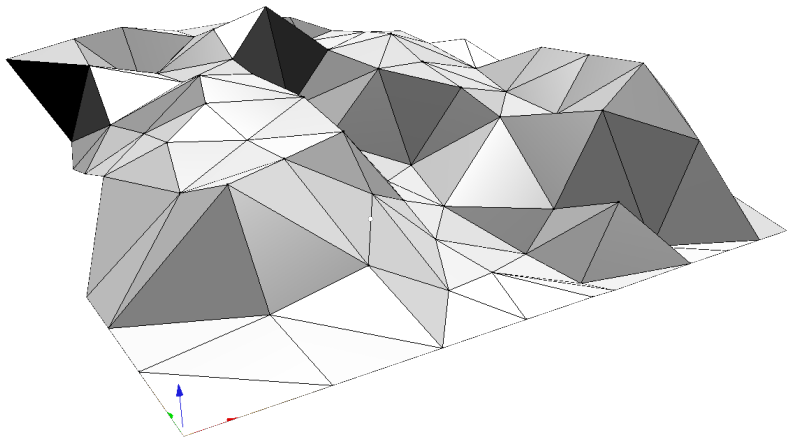


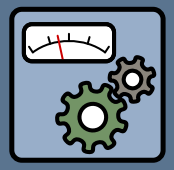
Scale Mediation:

Given discrete points

$$r_j = (x_j^{[1]}, x_j^{[2]}, \ldots, x_j^{[d]}), j = 1, \ldots, N$$

find a function $F(r)$ which passes through them:

$$F(r_j) = z_j, j = 1, \ldots, N$$

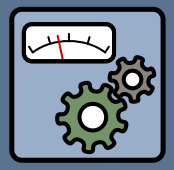


Subjective Perception can be:

Perspective **Physical** effects resulting from position in space, characteristics of observed phenomenon, etc.

Accuracy Limitations of the agent's **sensory input**.

Distortion **Psychological** or other distortions, possibly due to superimposing one class of input onto another.



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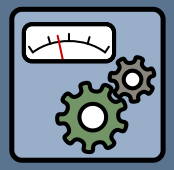

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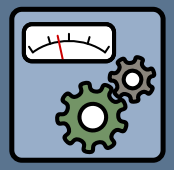

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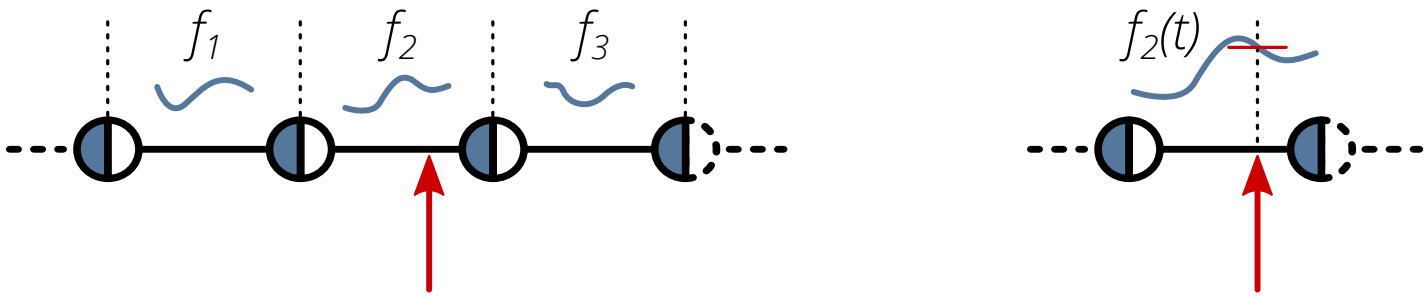


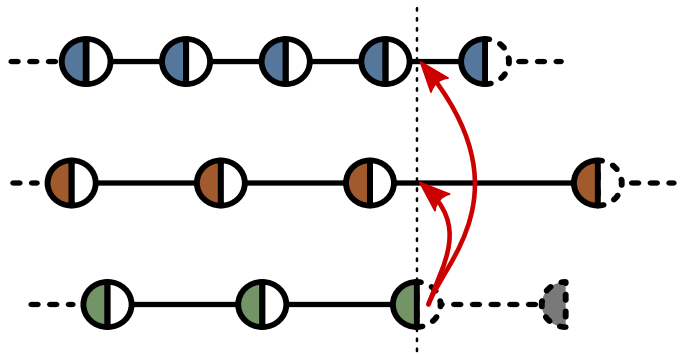
Contributions:

semantics:

- Efficient and Flexible **Agent-State Semantics**
- Globally-Synchronous, Locally-Subjective **Time Scales**
- **Circular Reference** Avoidance

scale mediation:

- Modular **Scale Mediation** Strategy



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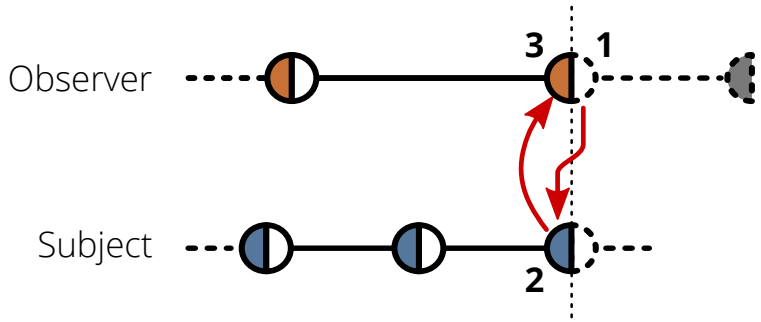

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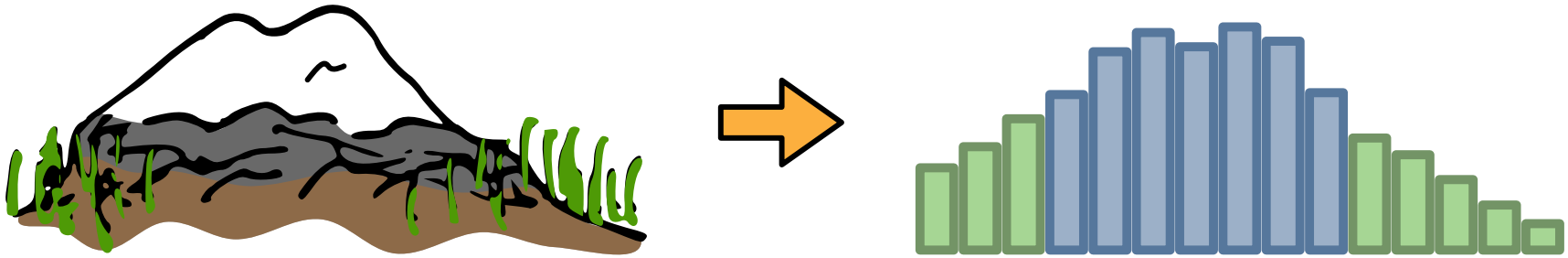

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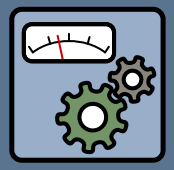
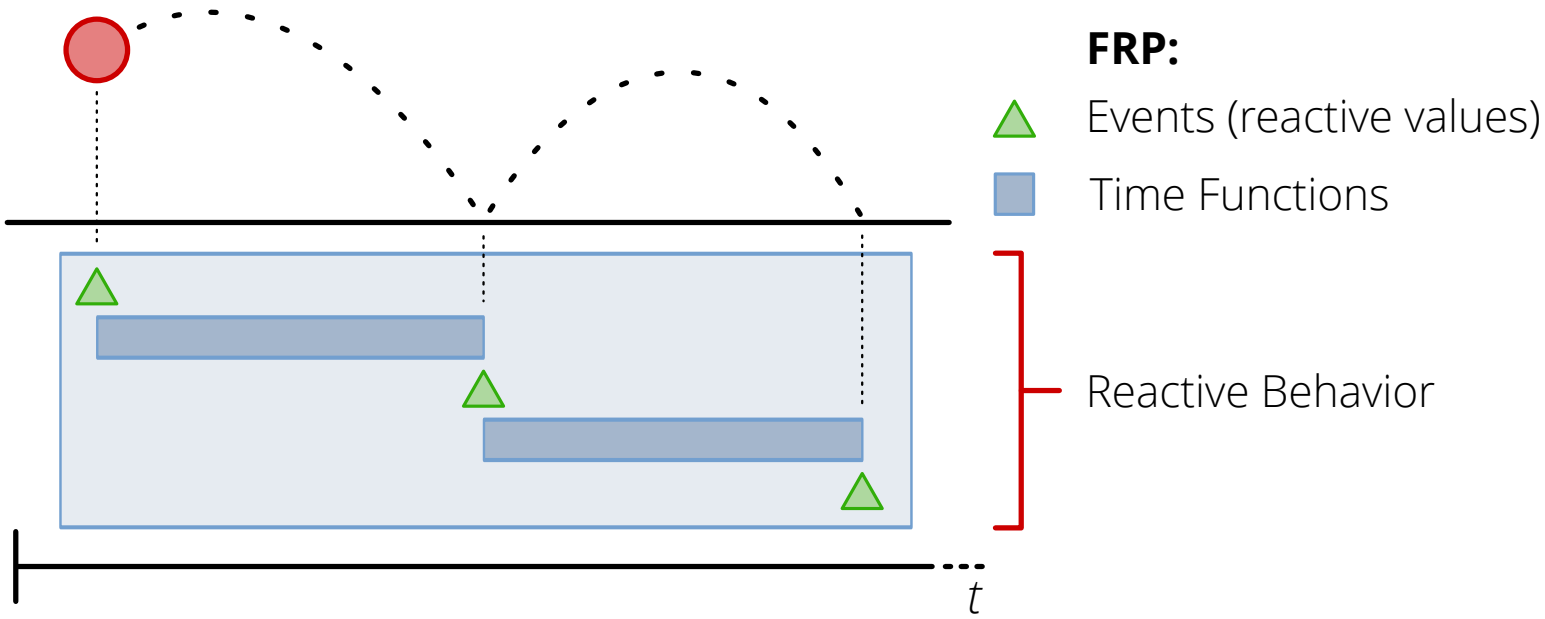


Semantics



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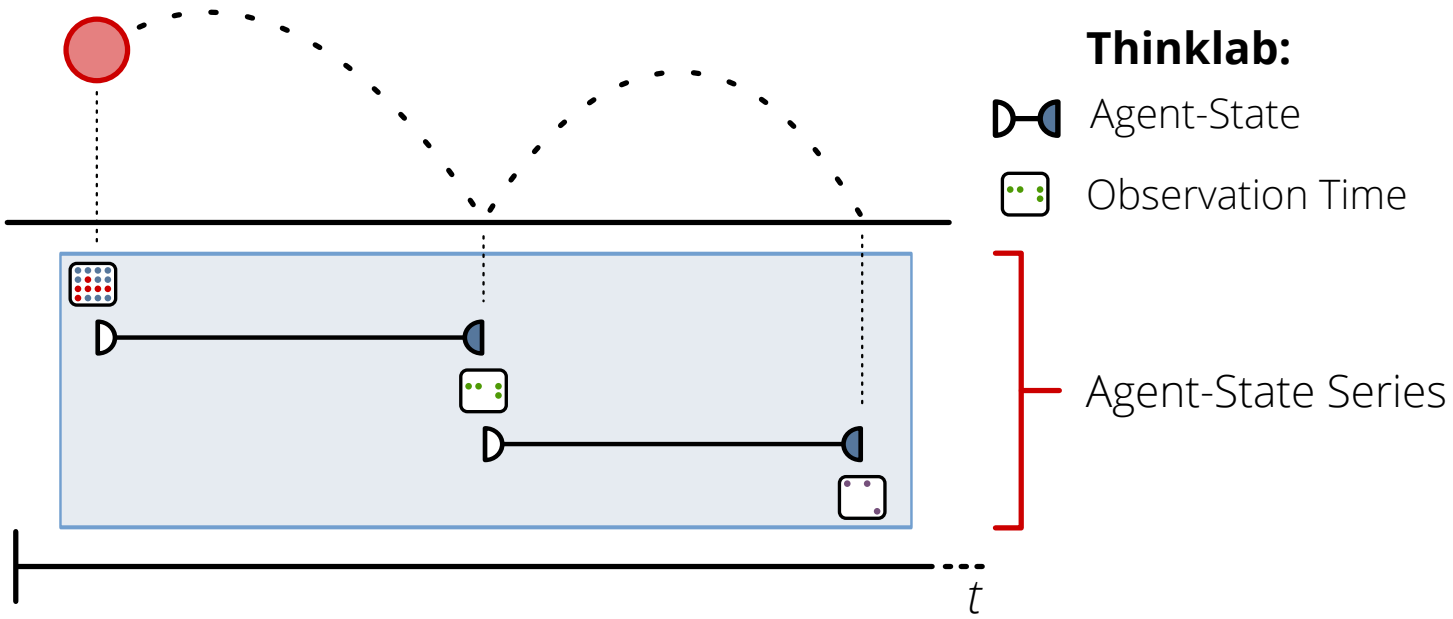
- To model agents' **state transitions**.
- Simple (easy implementation), flexible (decoupled), accurate
- Huge improvement over **homogeneous discrete models**.



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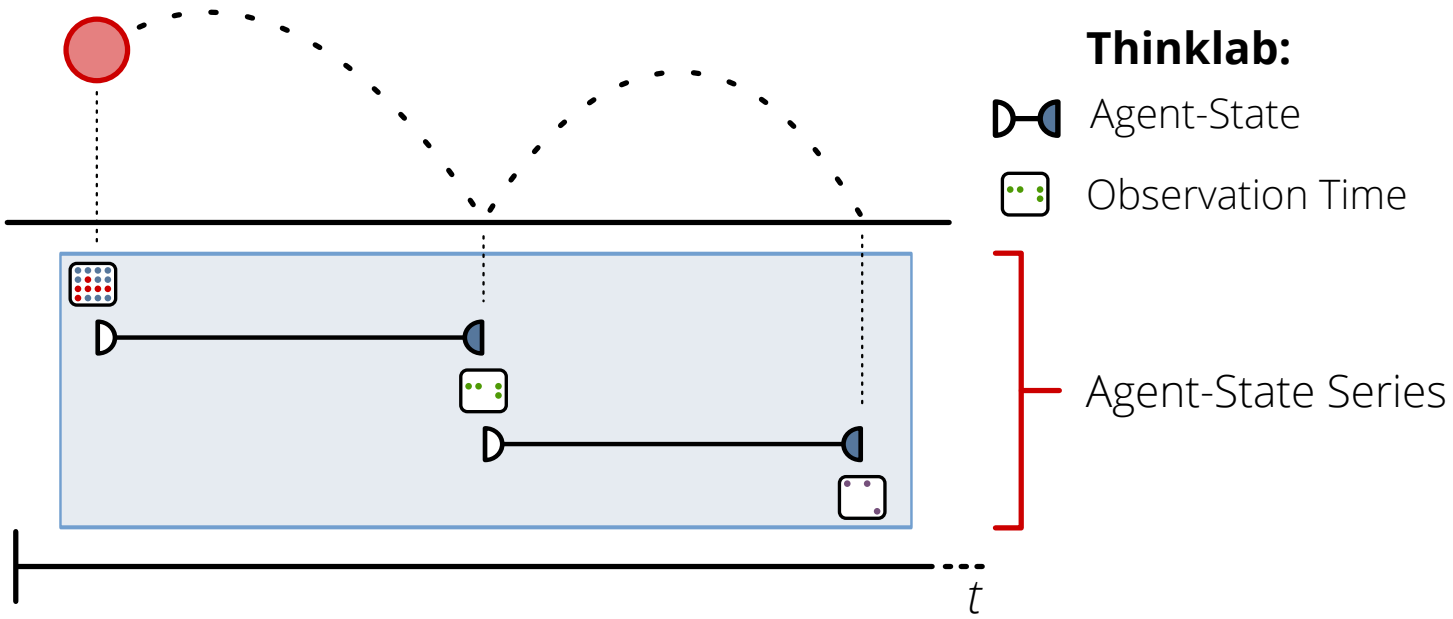

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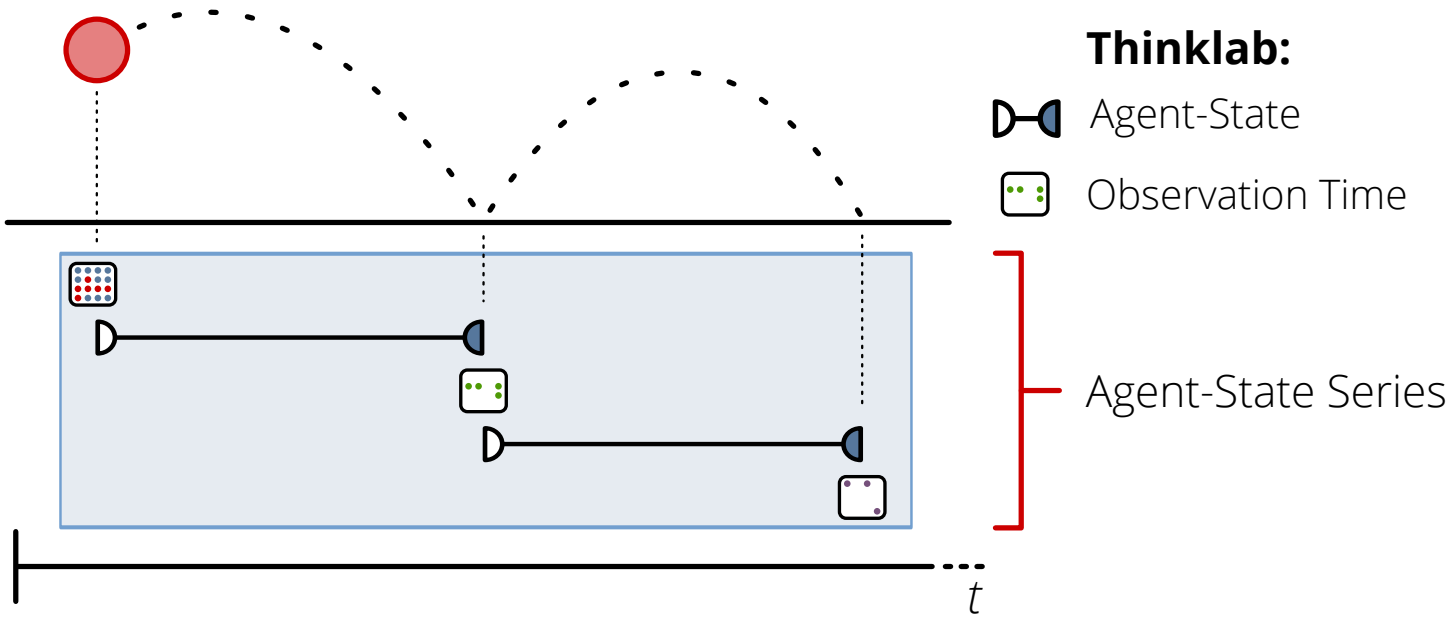

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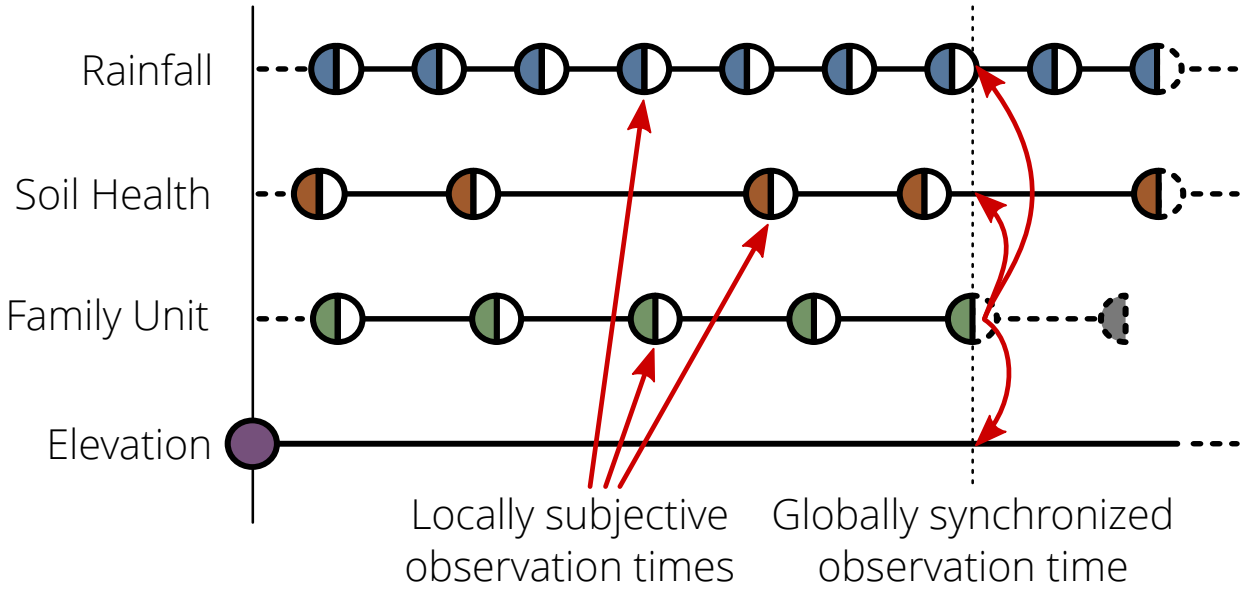
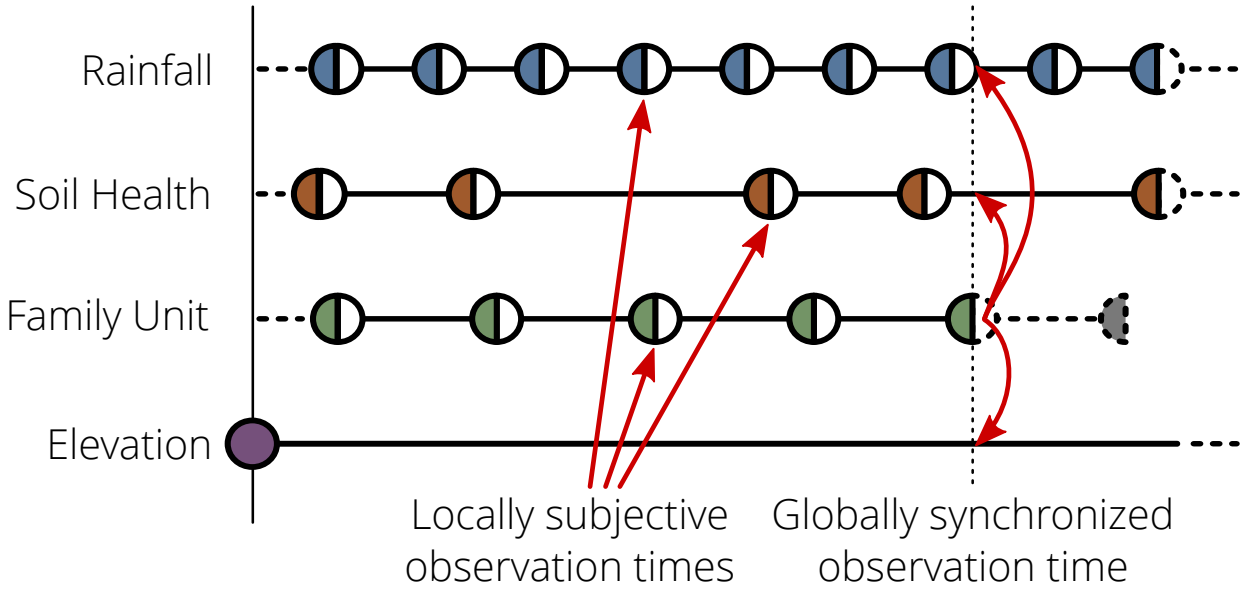


- **Synchronous** global clock
- **Subjective**, arbitrary-duration time steps
- Forward causality



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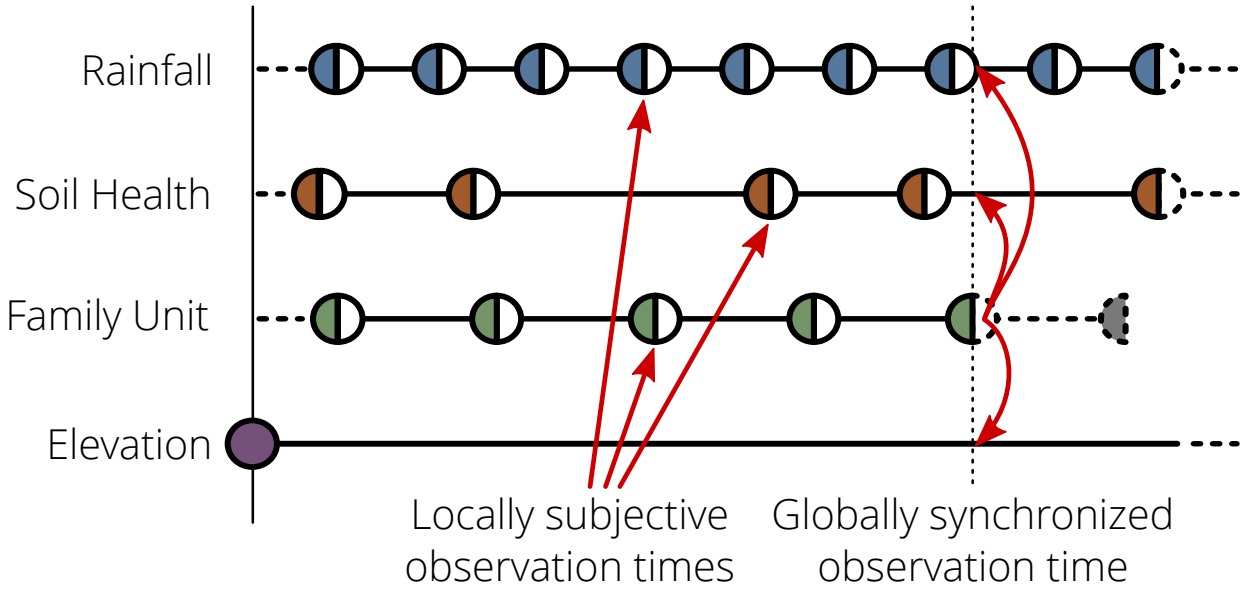

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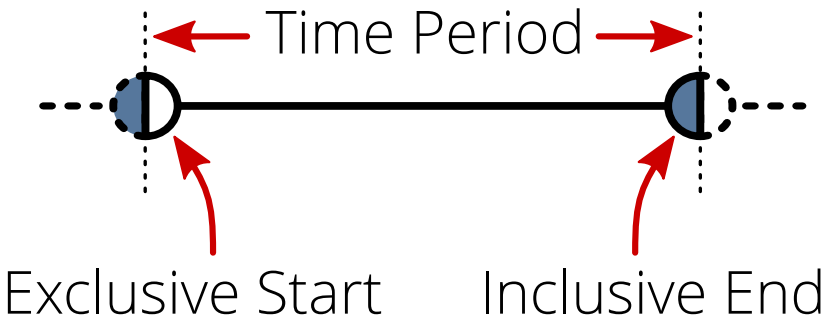
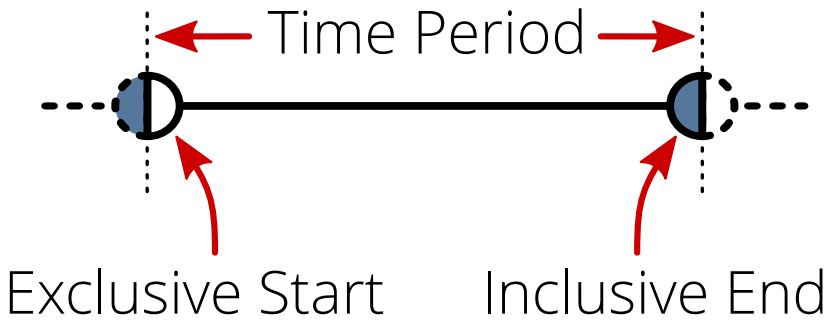


Exclusive-Inclusive Semantics:

- Read from the past, write to the future.
- Forces causality to be forward-directional.



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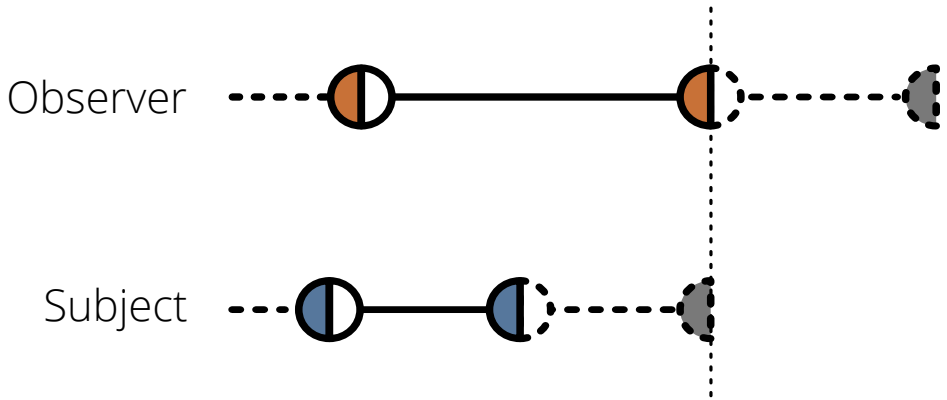
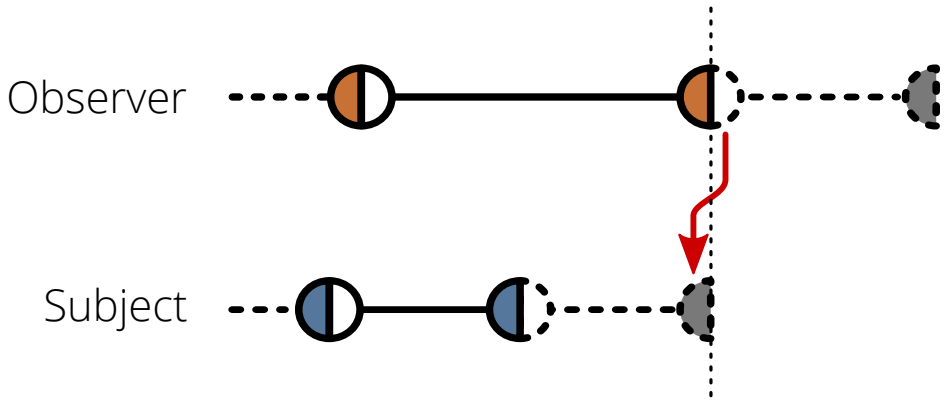


Cyclical Dependencies: Simultaneous observations and exclusive-inclusive semantics



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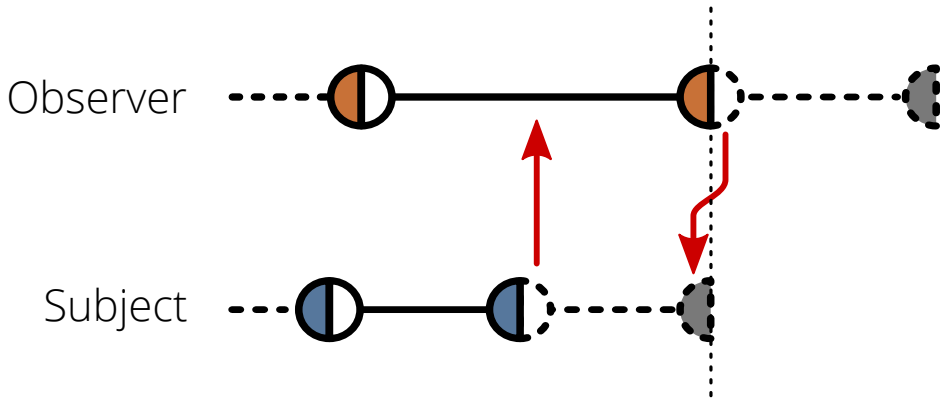

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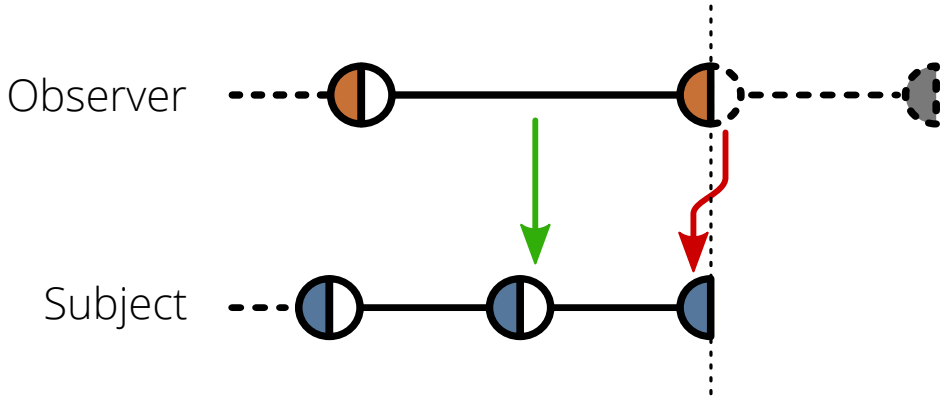

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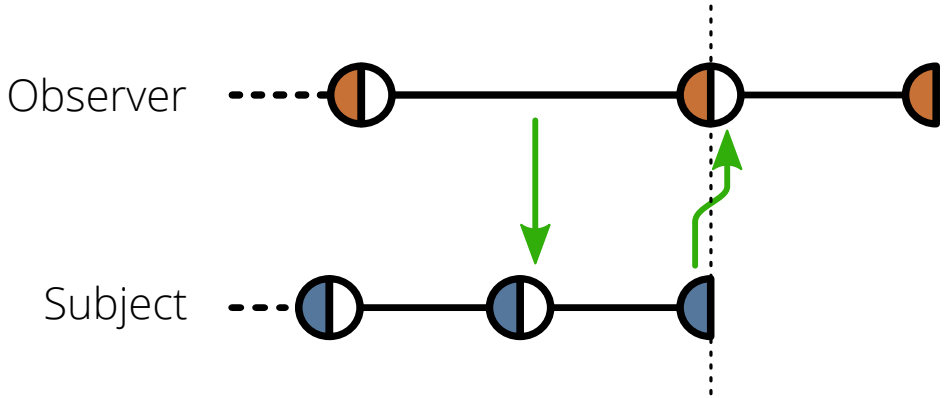

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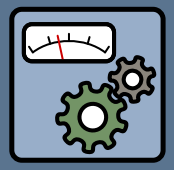
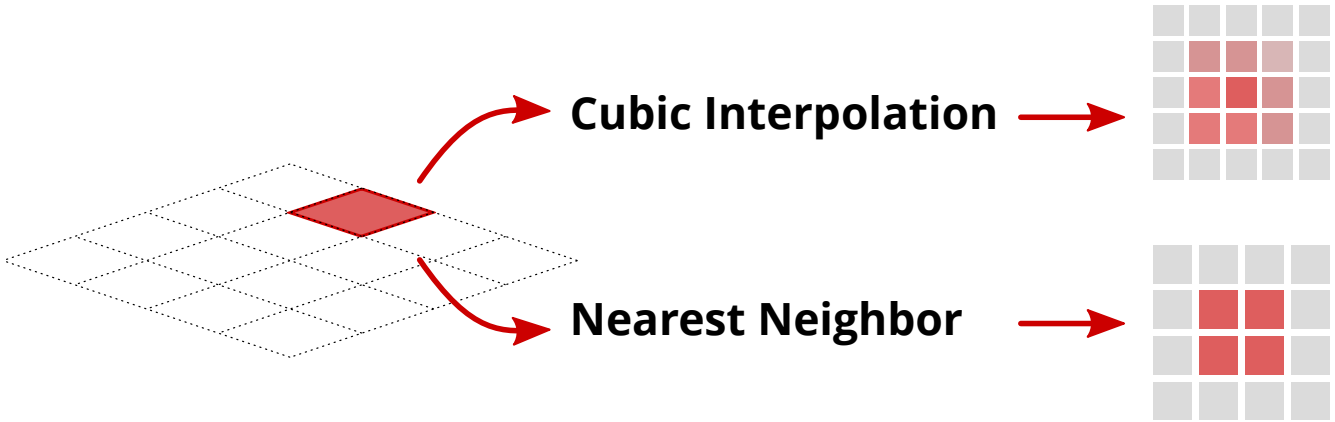
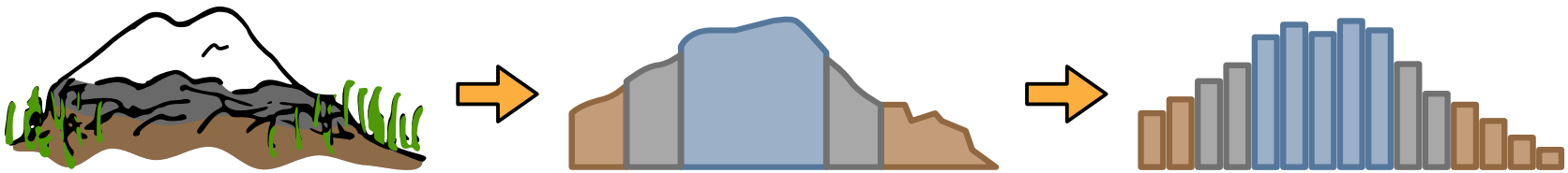


Scale Mediation

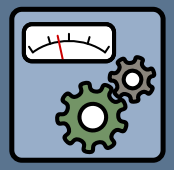


Mediation is specific to each combination of:

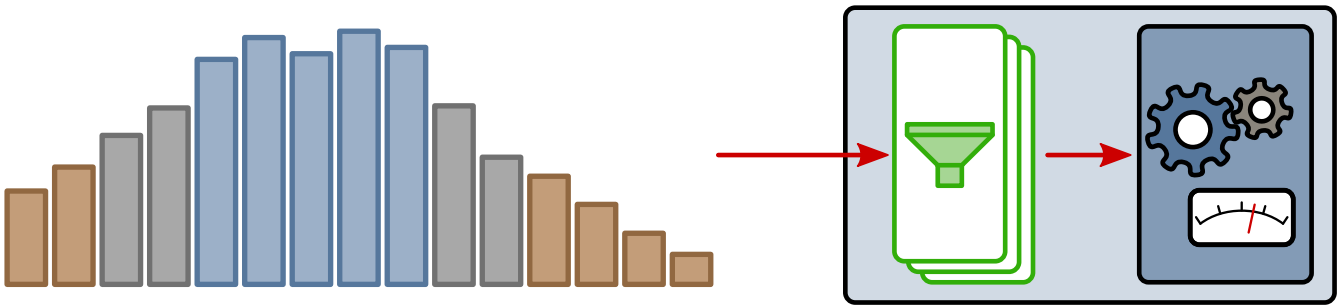
(**subject** × **property** × **mediation algorithm**)



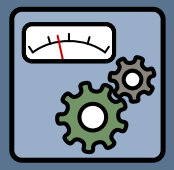
Intermediate Vector Representation: Inherent part to many interpolation mechanisms (we want to **optimize** for this use case!)



Perception

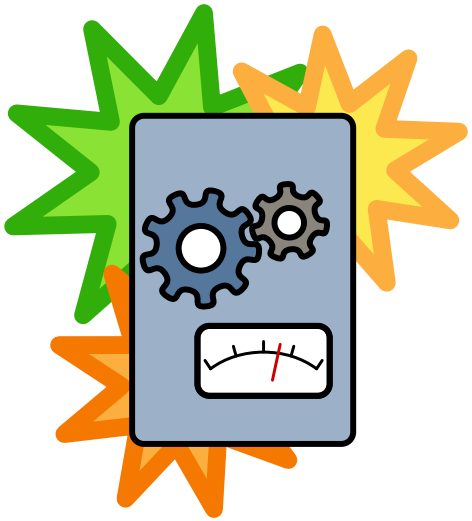


Perception: Internal to an agent (cf. scale Mediation: **external** to an agent).



Execution Model

Creation:
At simulation startup,
or by other agents



Agent Life Cycle: Birth → State Transitions → Death

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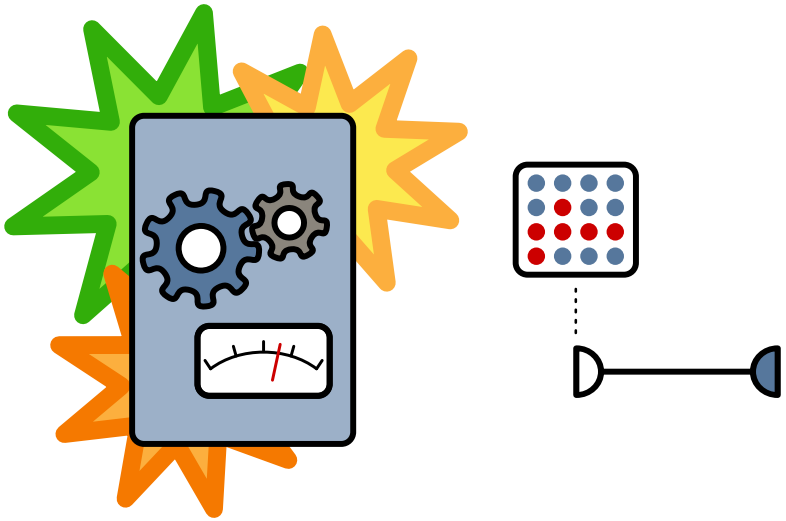
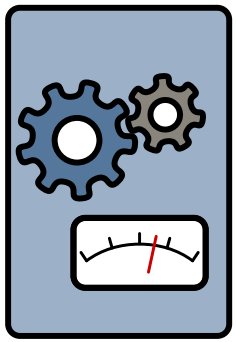
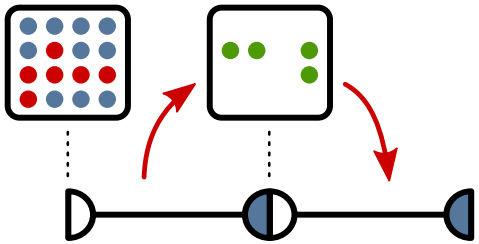


Agent Life Cycle: Birth → State Transitions → Death

Observation + Agent-States:
The daily life of an agent





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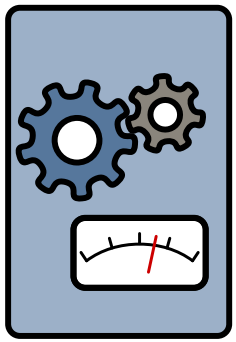

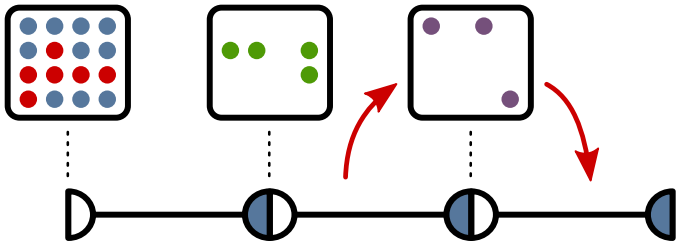

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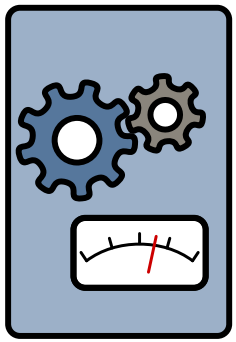
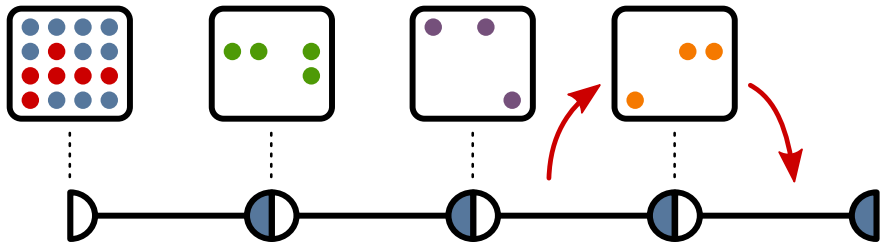
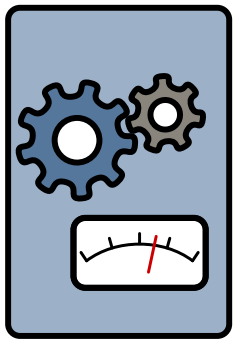
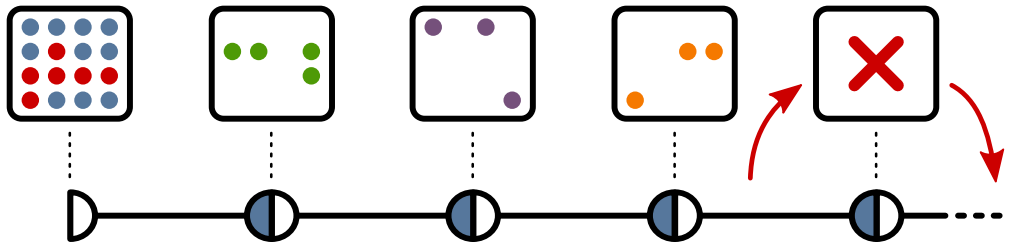




Agent Life Cycle: Birth → State Transitions → Death

Death:
Caused by agent's temporal scale, or by run-time events





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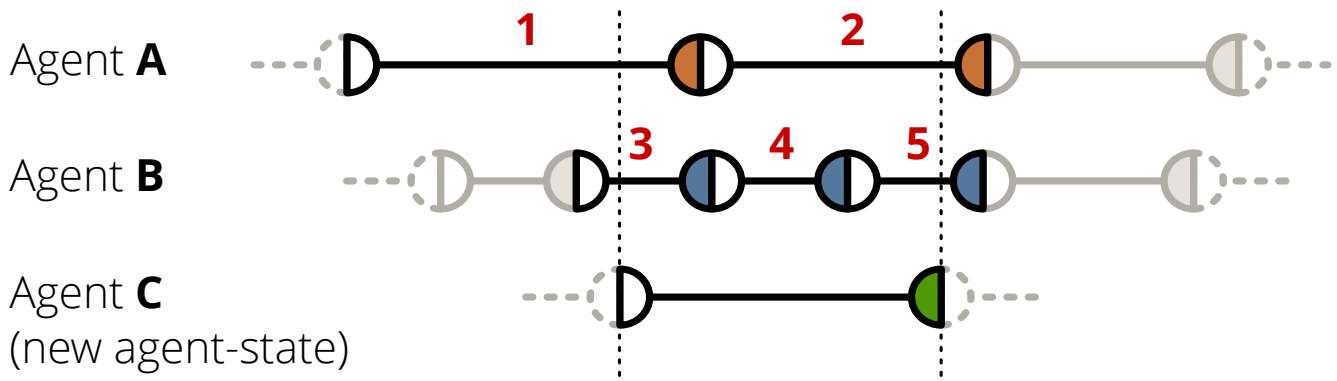
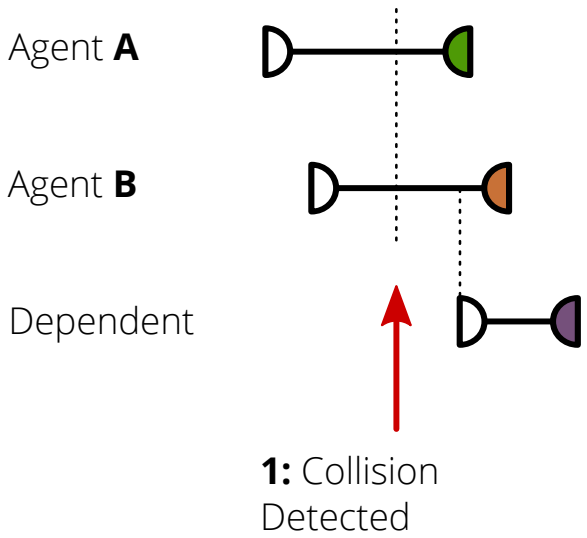
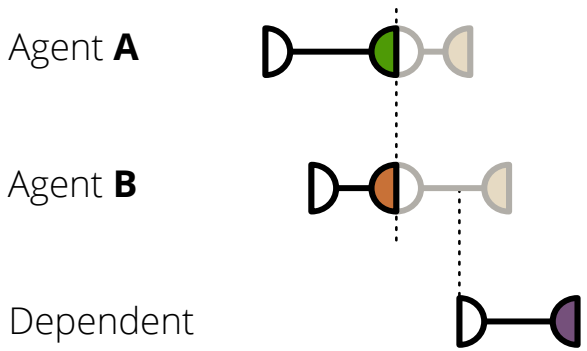


Collision Detection: For every pair of overlapping agent-states

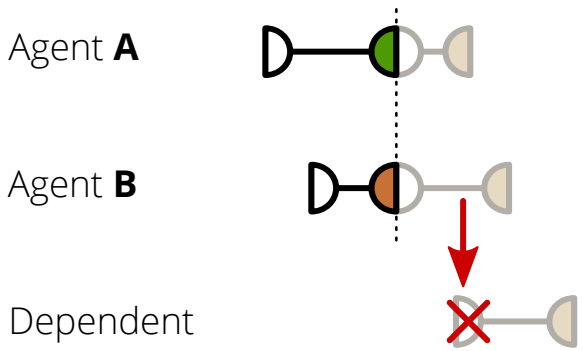


Collision Invalidation: Recursively, based on causal relationships



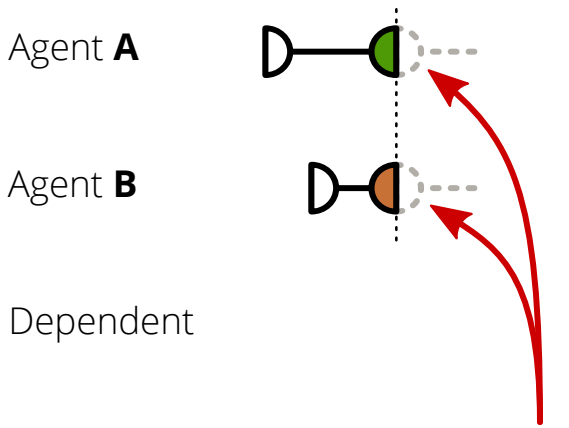
2: Agent-states terminated at collision time

Collision Invalidation: Recursively, based on causal relationships



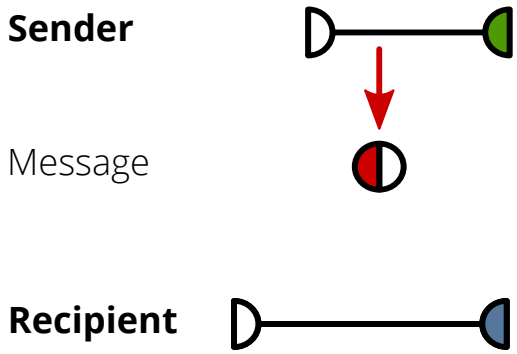
3: Recursively invalidate dependent agent-states

Collision Invalidation: Recursively, based on causal relationships

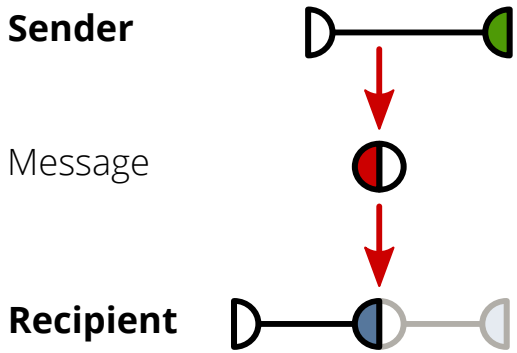


4: New collision-aware observation tasks created

Collision Invalidation: Recursively, based on causal relationships

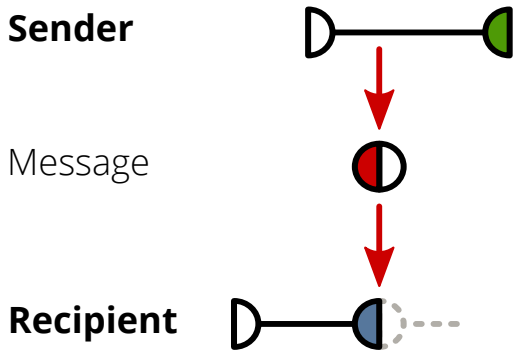


Messaging: Collision object containing “message” agent



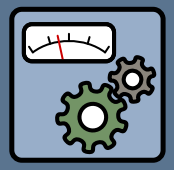
2: Task is **queued** and **executed**

Messaging: Collision object containing “message” agent

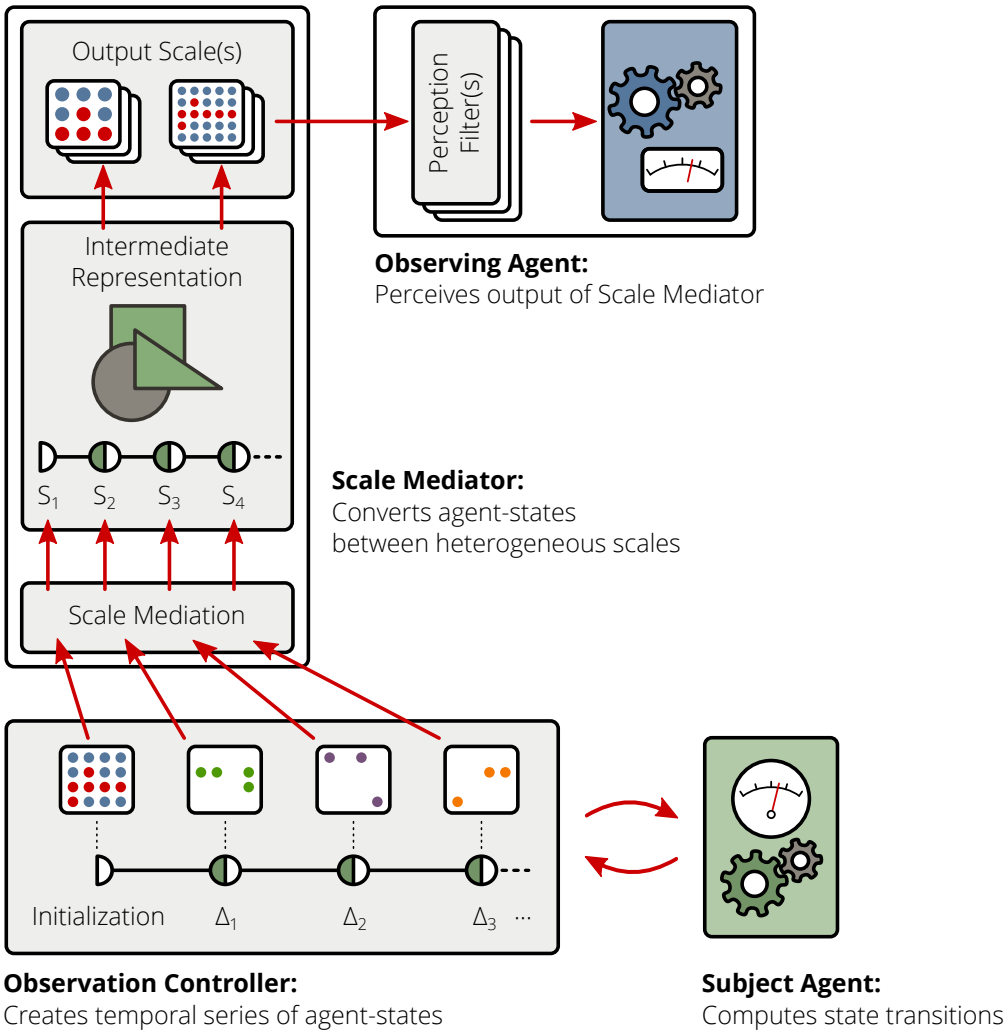


3: Observation and
recursive invalidation
as in normal collisions

Messaging: Collision object containing “message” agent



Contributions (again)



semantics:

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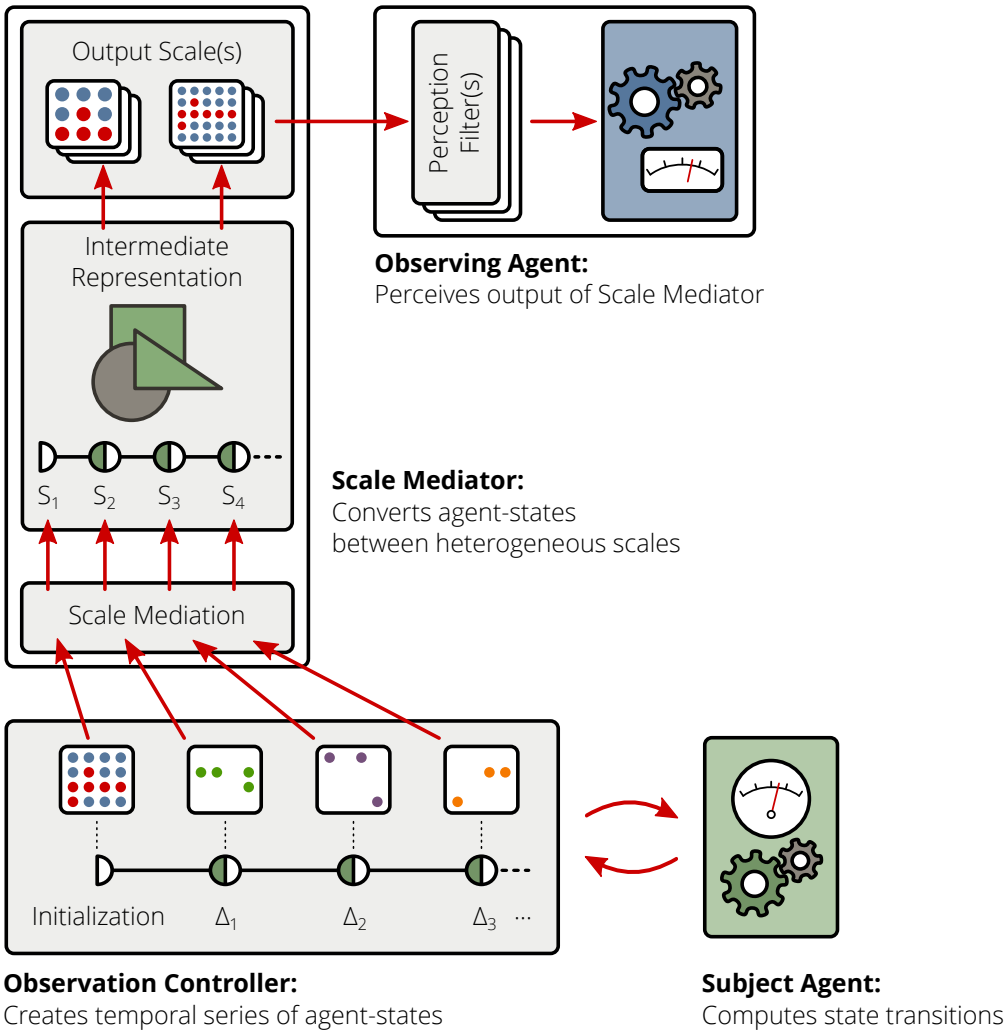
scale mediation:

- Modular **Scale Mediation** Strategy



Observing Agent:
Perceives output of Scale Mediator

Scale Mediator:
Converts agent-states between heterogeneous scales

Observation Controller:
Creates temporal series of agent-states

Subject Agent:
Computes state transitions

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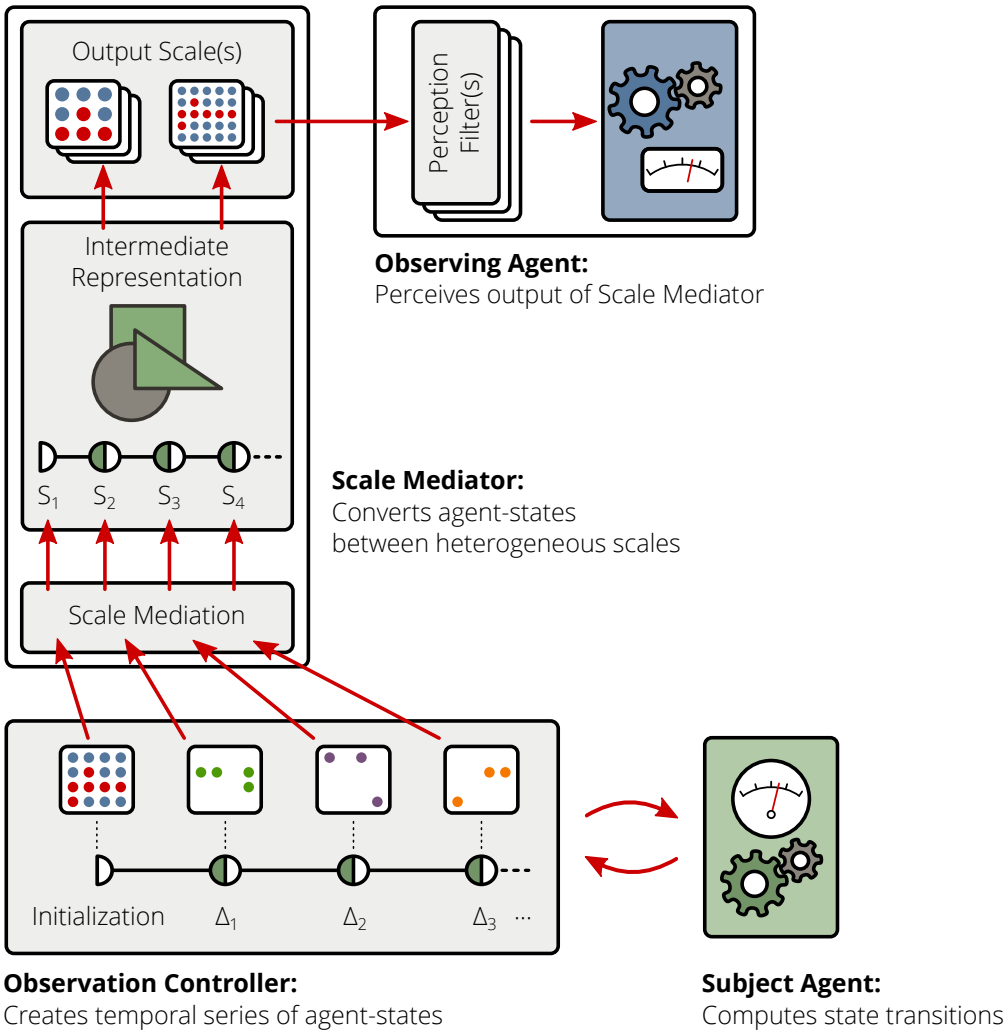

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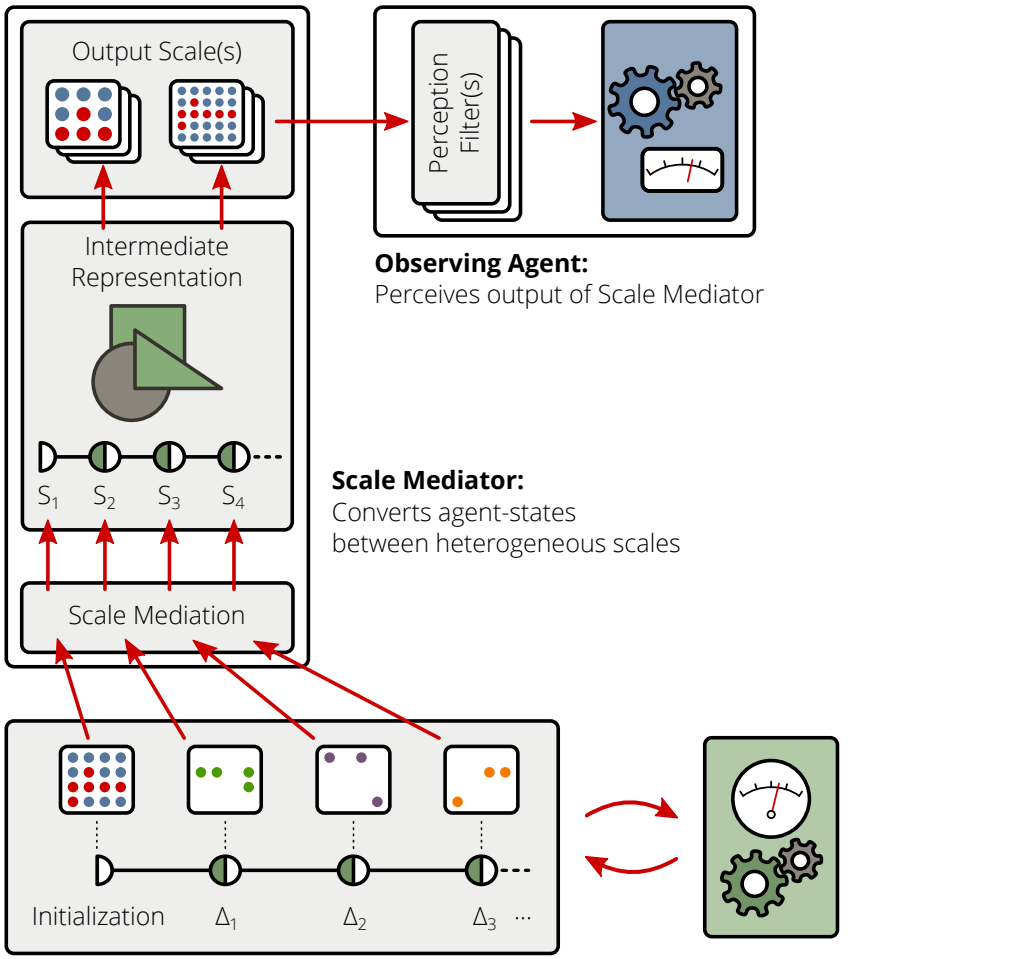

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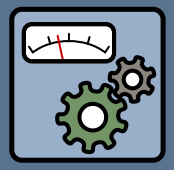
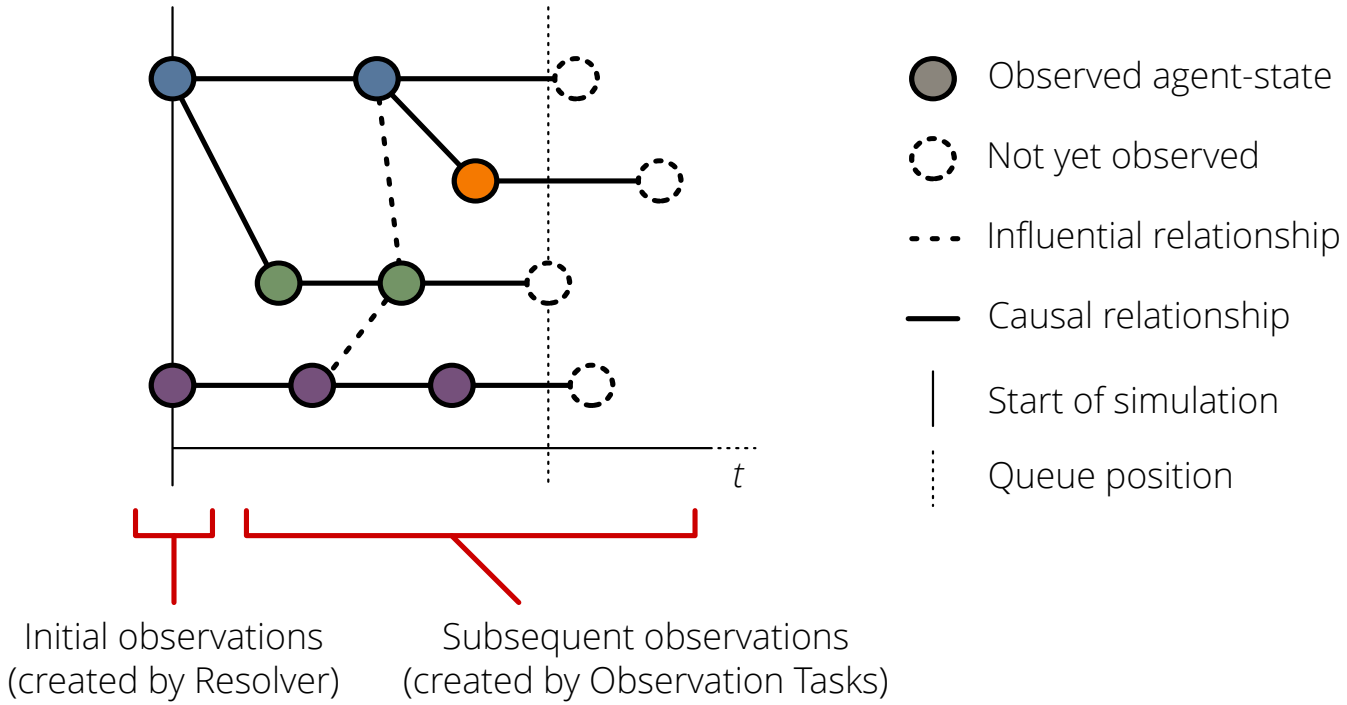
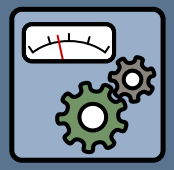
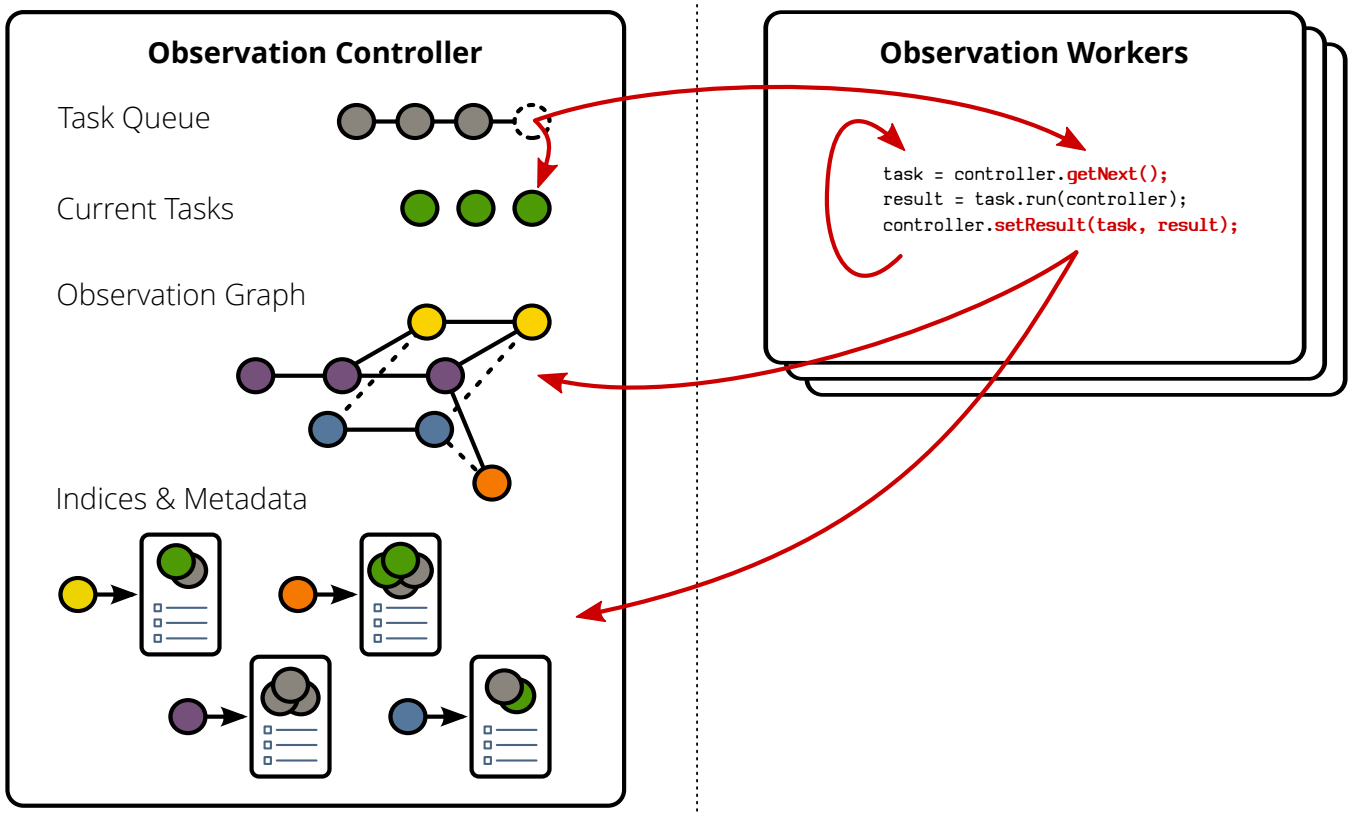


Implementation

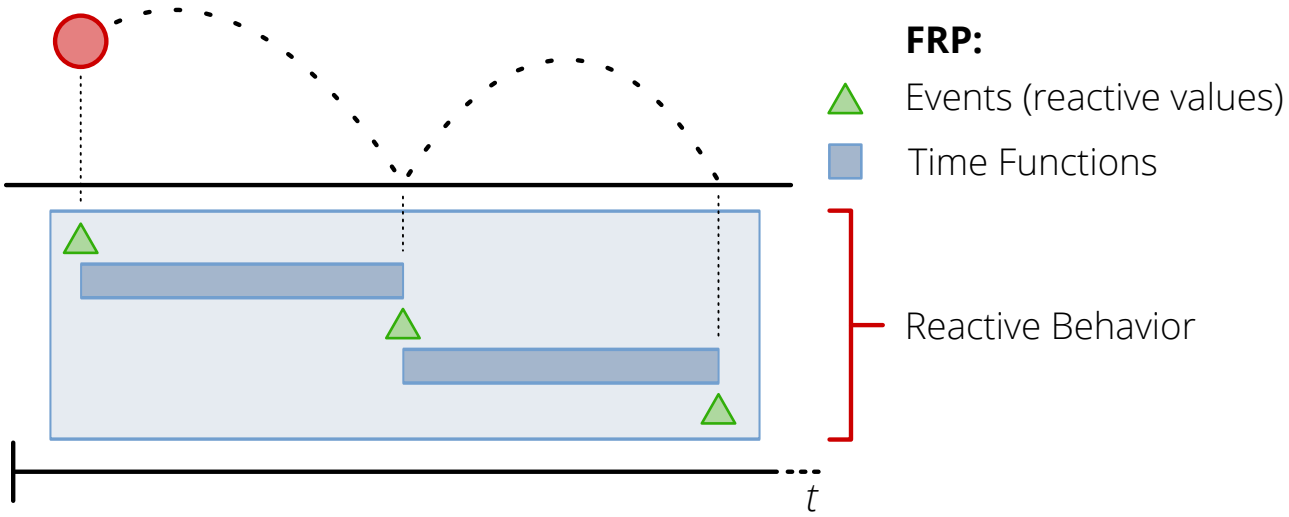


Observation Graph: Central repository for **agent-states**

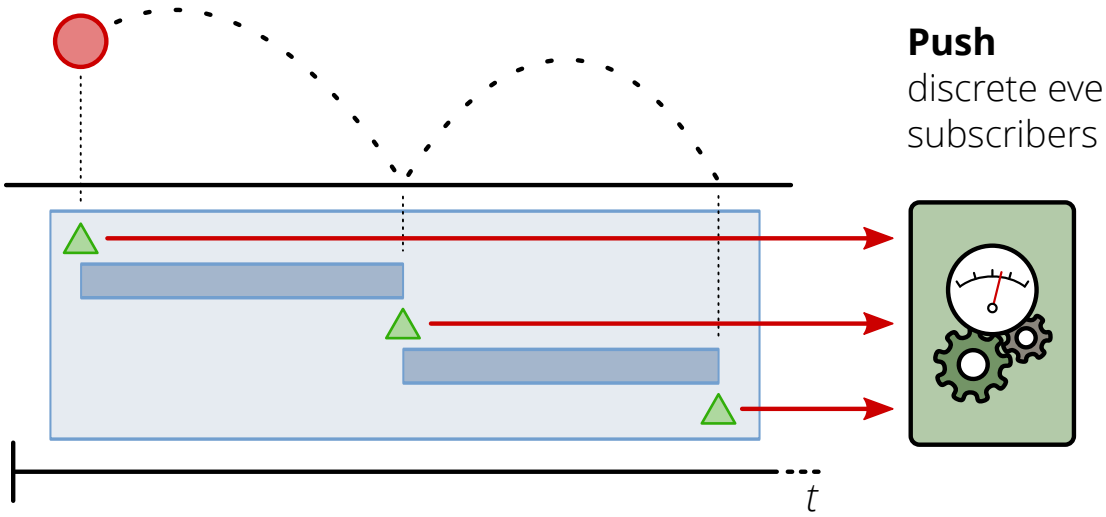




Distributed Processing: Observation **workers** executed on different threads. Consistency is maintained through observation **controller**.

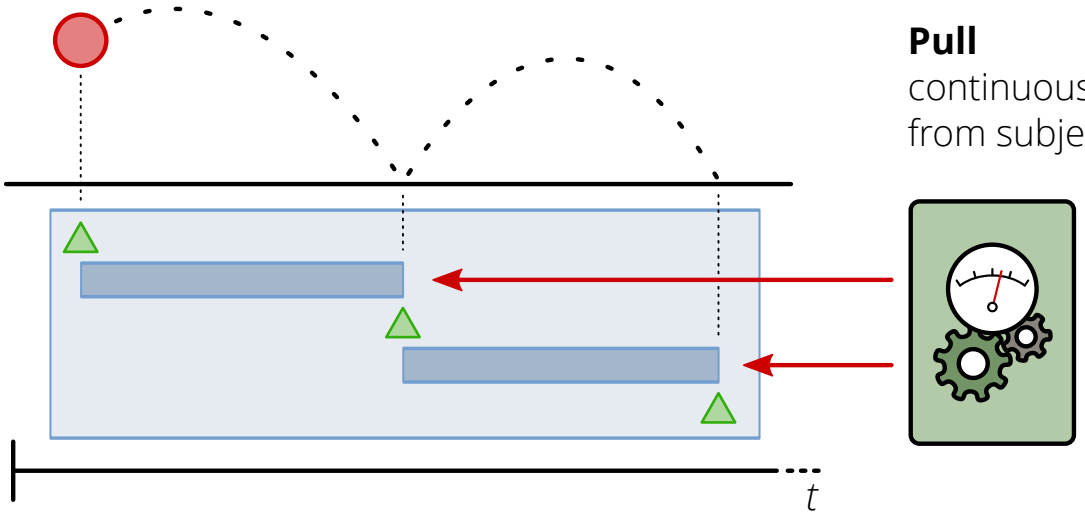


Push-Pull FRP: publish/subscribe + functional evaluation



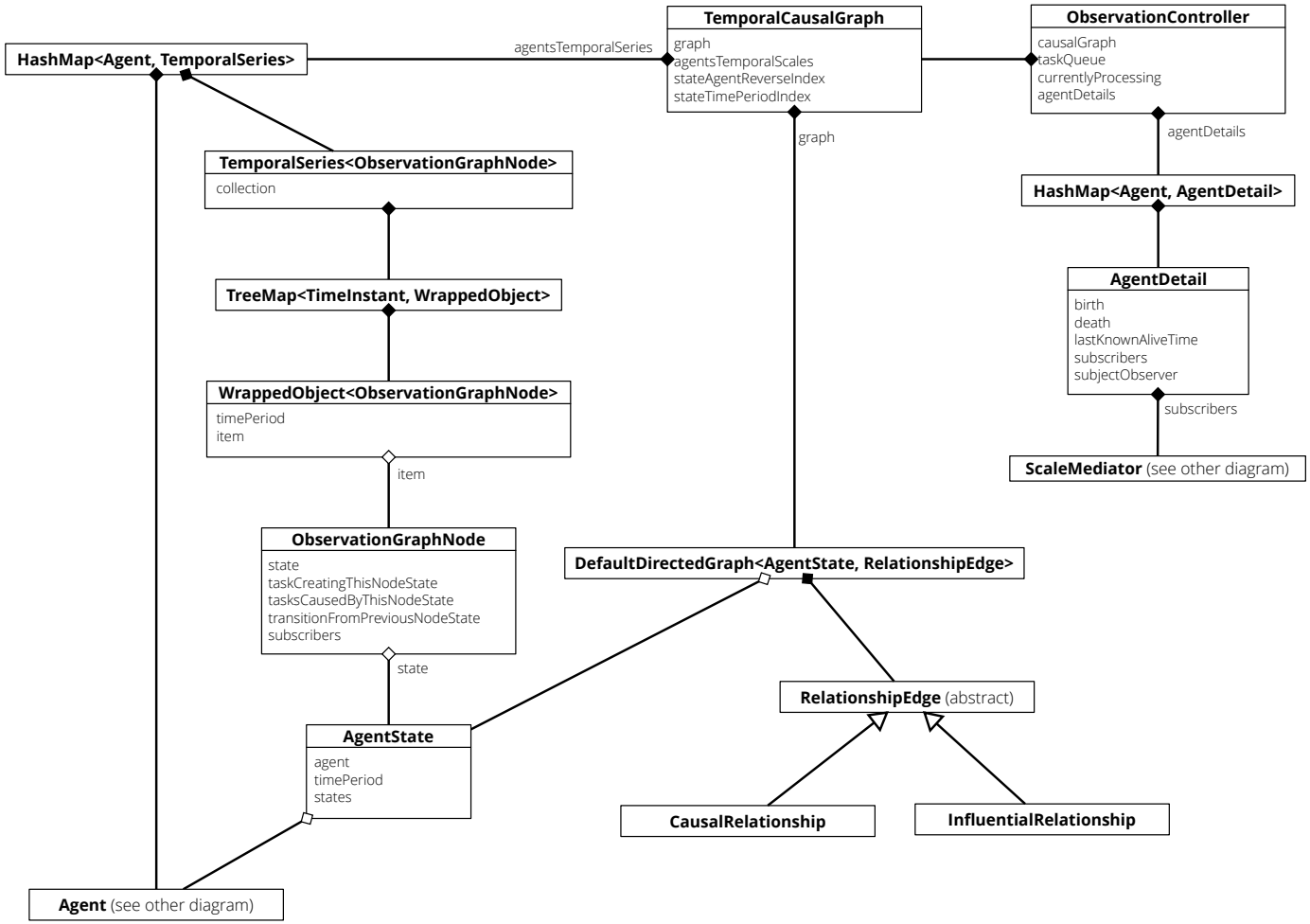
Push
discrete events to
subscribers (observers)

Push-Pull FRP: publish/subscribe + functional evaluation

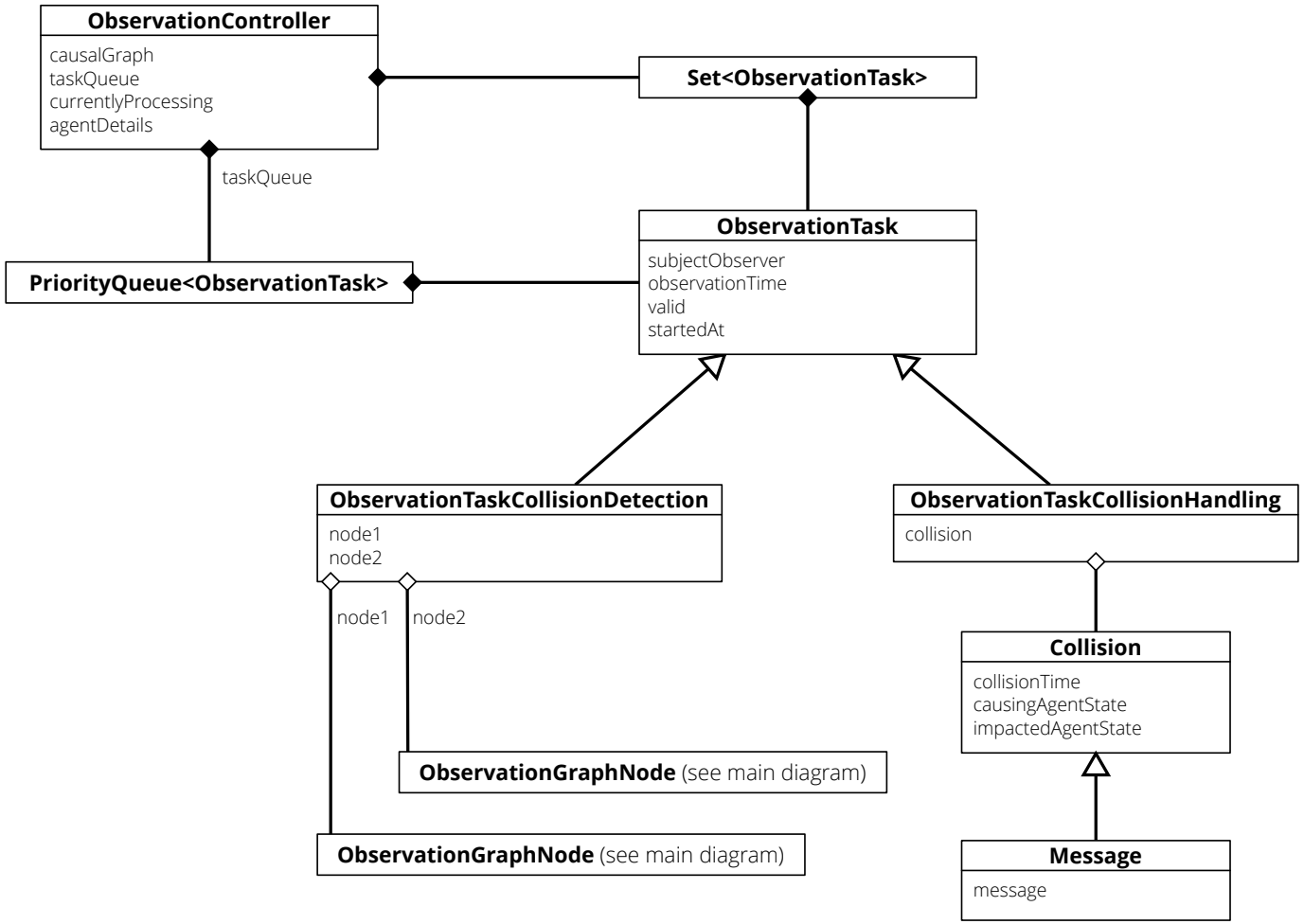


Pull
continuous time functions
from subjects

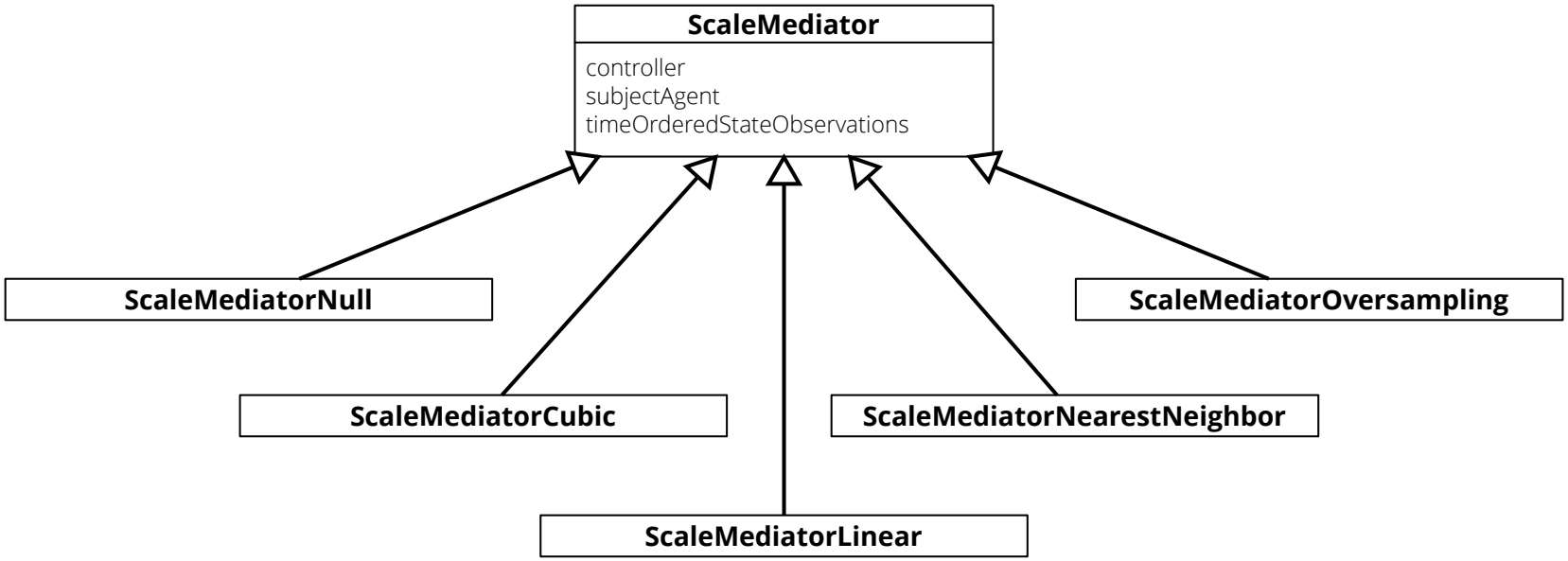
Push-Pull FRP: publish/subscribe + functional evaluation



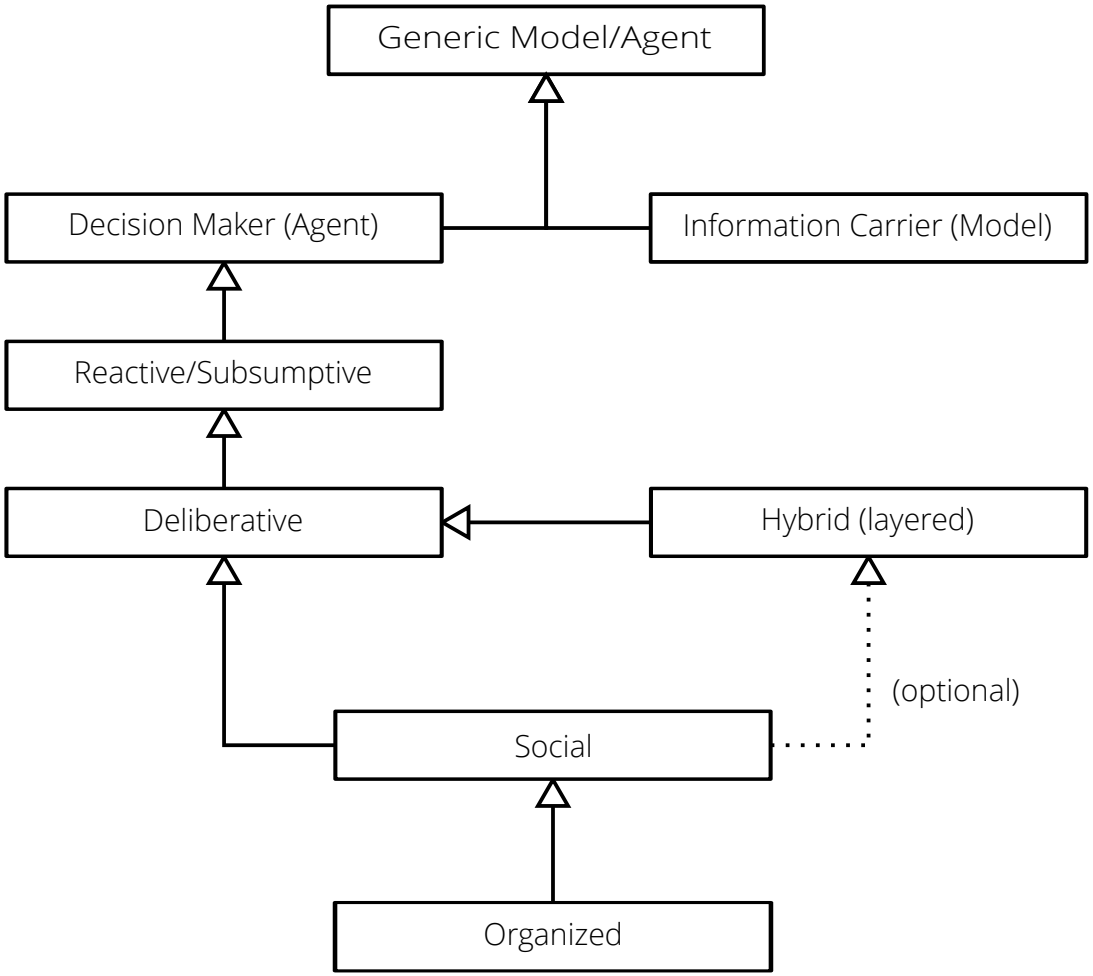
UML Diagram: Overview



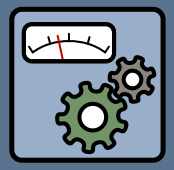
UML Diagram: Tasks/Collisions/Messaging



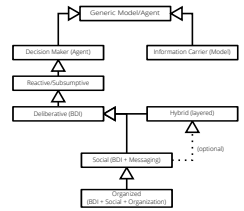
UML Diagram: Scale Mediators

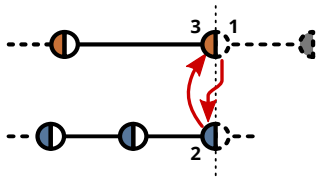


UML Diagram: Agent Types

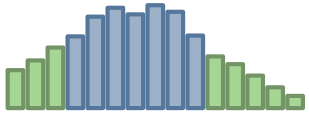


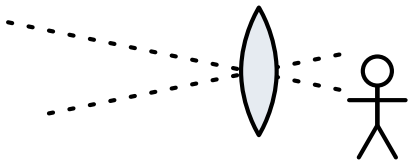
Summary





Semantics

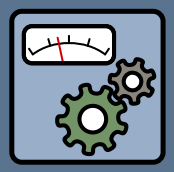


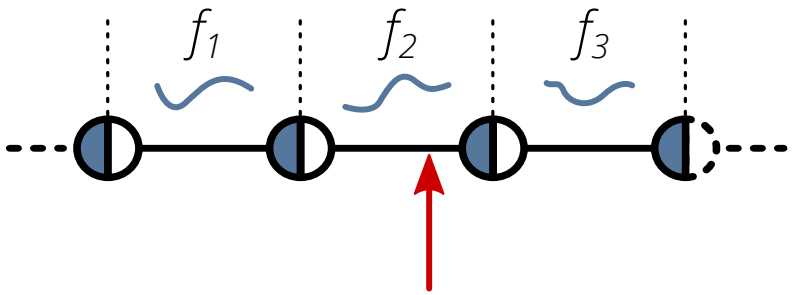


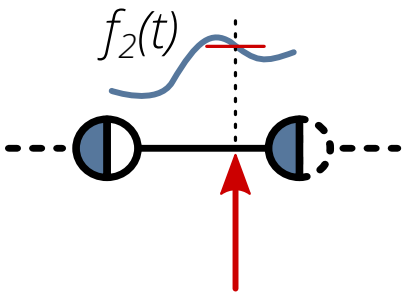
Scale Mediation

Perception

Sub-Problems addressed by our contributions







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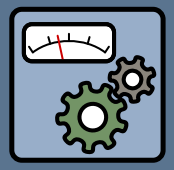

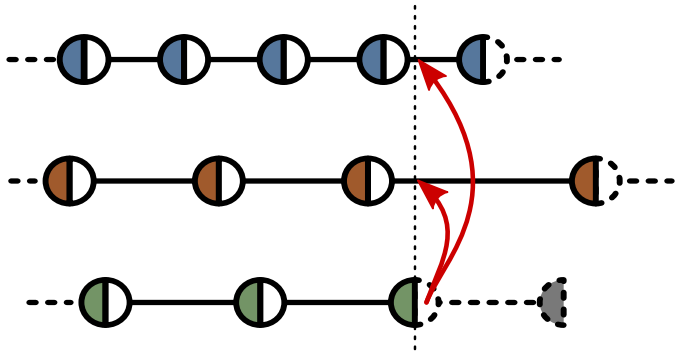

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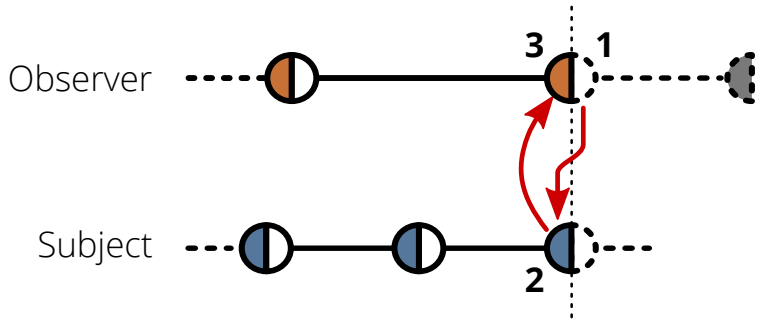

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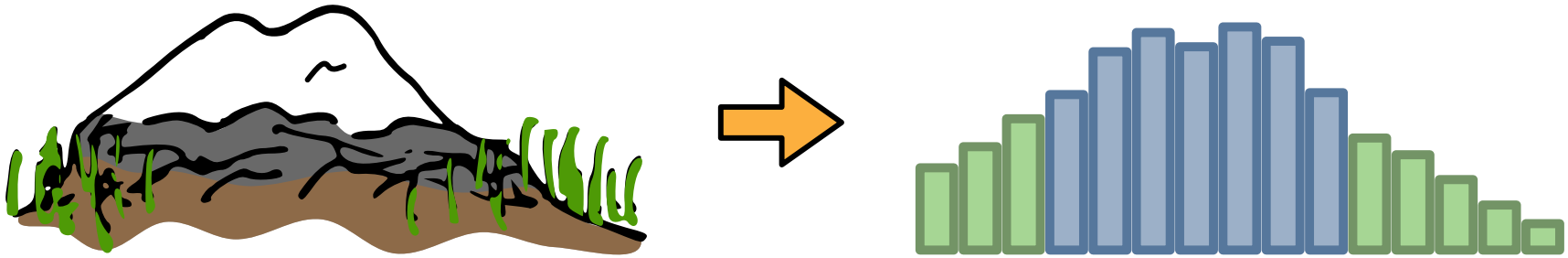

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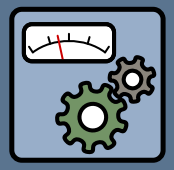
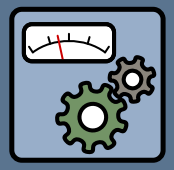


Future Work

Differential Temporal Transitions Apply **differential updates** to **intermediate vector representation** (don't re-generate full agent-states)

Collision Detection Implement agent- and concept-specific detection algorithms

Other Items More detail in the full paper



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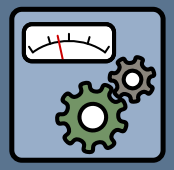

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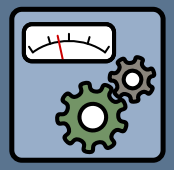

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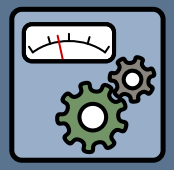
In *International Conference on Functional Programming*, 1997.

Conal M Elliott.
Push-pull functional reactive programming.
In *Proceedings of the 2nd ACM SIGPLAN symposium on Haskell*, pages 25–36. ACM, 2009.

Lubos Mitas and Helena Mitasova.
Spatial interpolation.
In Paul A. Longley, Michael F. Goodchild, David J. Maguire, and David W.Rhind, editors, *Geographical Information Systems: Principles, Techniques, Management and Applications*, chapter 34, pages 481–492. Wiley, 1999.



Thank You

Please put your **name** and **email** on the contact sheet!

J. Luke Scott
jlukescott@gmail.com

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