Modelling and Inference for Pandemic Preparedness Workshop
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A Software Engineer's Approach to Agent-Based Modelling

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Agenda

- Introduction
  - My understanding of ABM
- Statecharts
  - Components (states; transitions; triggers)
  - Example (adaptive architecture)
- Engineering Agent-Based Social Simulations (ABSS)
  - What is it (co-creation in a structured way)
  - Example (adaptive architecture)
- Multi-Method Modelling
  - Modelling pandemic preparedness using multiple paradigms
  - Example (healthcare)
  - Simulating the climate ichange mpact of the entire US population using multiple paradigms

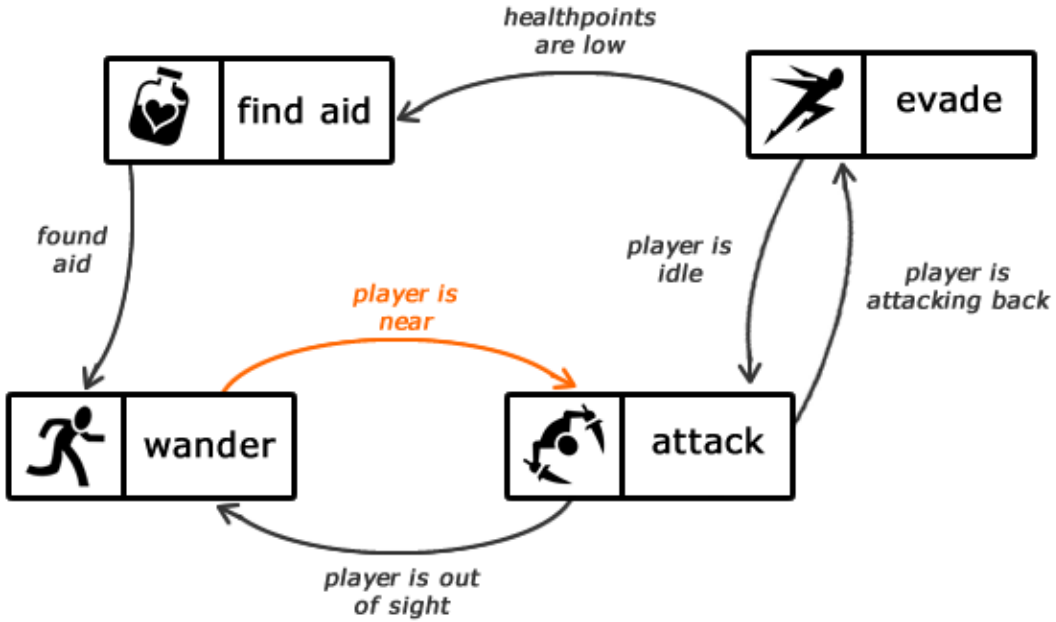
Agent-Based Modelling

- Agent-Based Modelling
  - A complex system is represented by a **collection of agents** that are programmed to **follow some behaviour rules** and the **system properties emerge** from its **constituent agent interactions**
    - Useful for studying social and economic phenomena
    - Employs a bottom-up approach
    - Captures the dynamics of a system over time
    - Captures emergent phenomena at the macro level

  - Agents can represent individuals, households, firms, organisations, nations ...

Statecharts

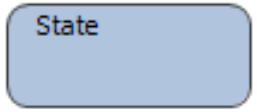
- Graph, where the nodes are the states, and the edges are the transitions
  - Statechart representing the brain of an enemy



Source: https://code.tutsplus.com/finite-state-machines-theory-and-implementation--gamedev-11867t

Statecharts for Representing States and Behaviours

- Typical elements of a statechart
  - States
    - Represents a location of control with a particular set of reactions to conditions and/or events
    - Examples
      - Cup can be in state **full** or **empty**
      - Person can be in state **idle** or **busy**



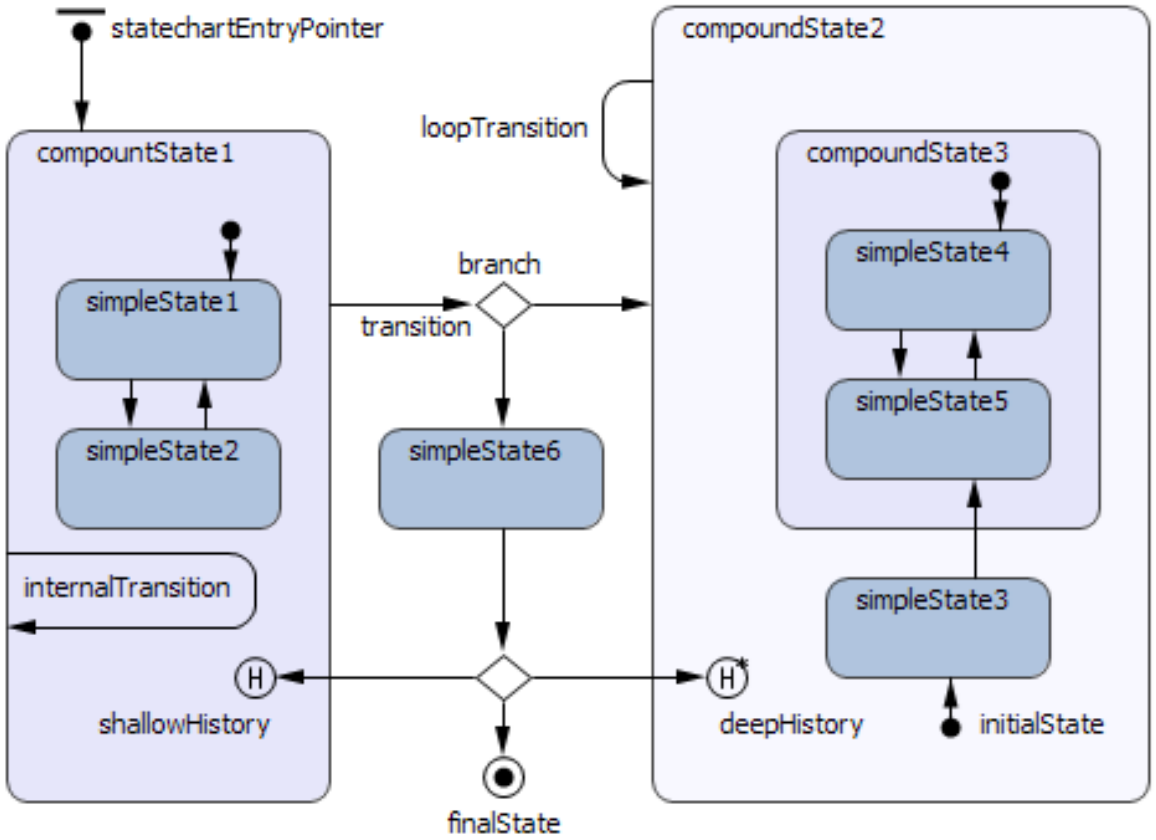
  - Transitions
    - Movement between states, triggered by a specific events

      - Such events can be: timeouts; rates; conditions; messages; agent arrivals
- Difference between flowcharts and statecharts?

  Flowchart: Used to model the flow of control in a **system** or **process**

  Statechart: Models the states an **object** can be in and the transitions between those states

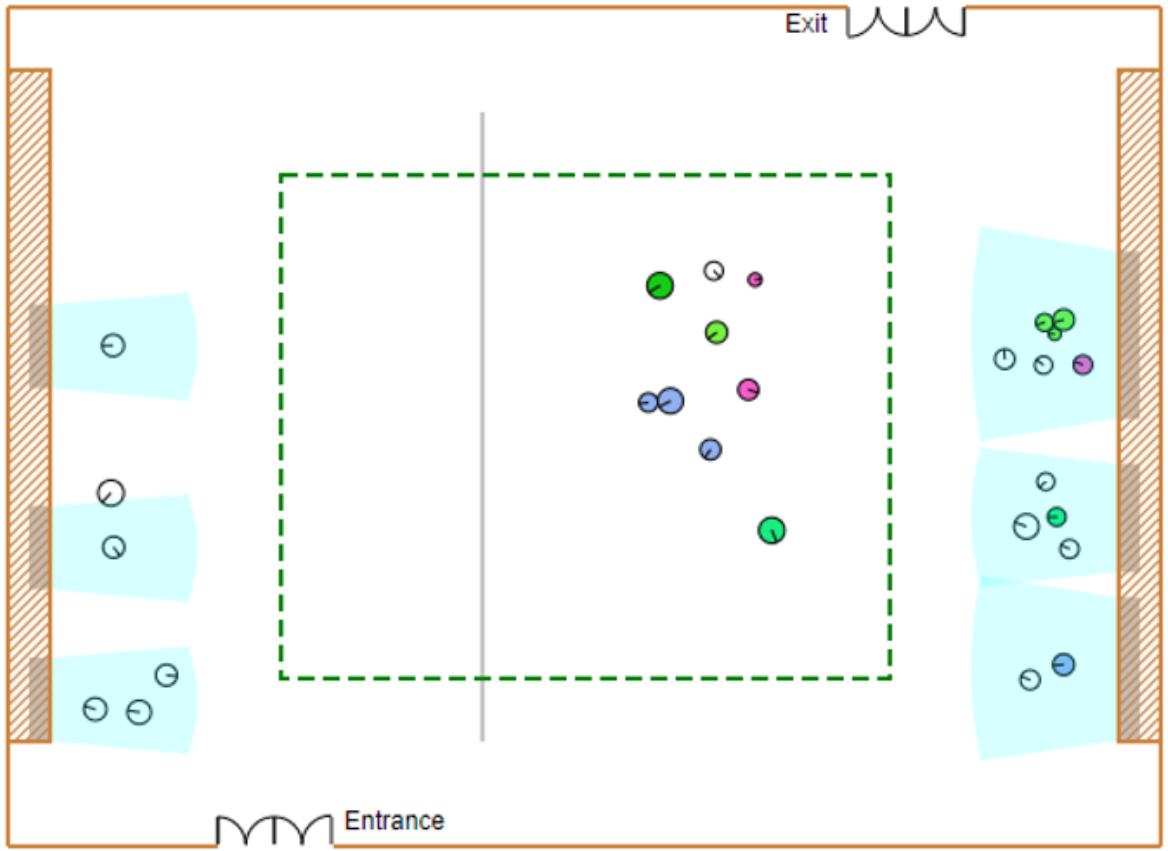
Statecharts for Representing States and Behaviours

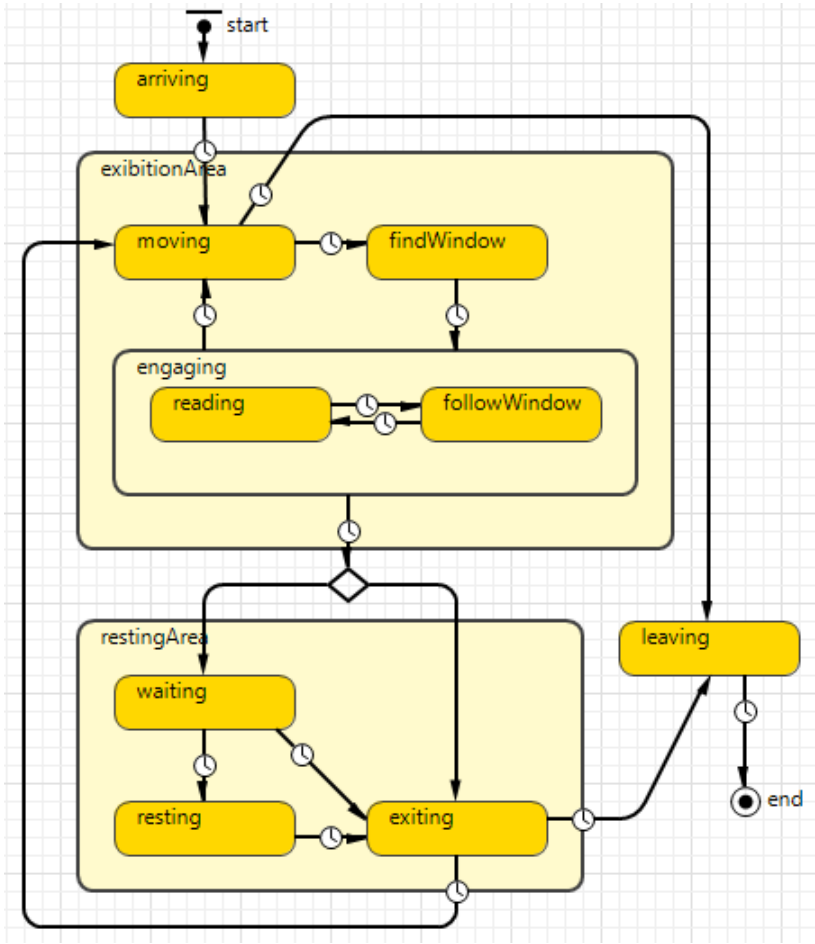


Source: AnyLogic Help

- It is possible to have multiple statecharts in one agent
  - Physical state machine
  - Mental state machine

Example: Adaptive Architecture



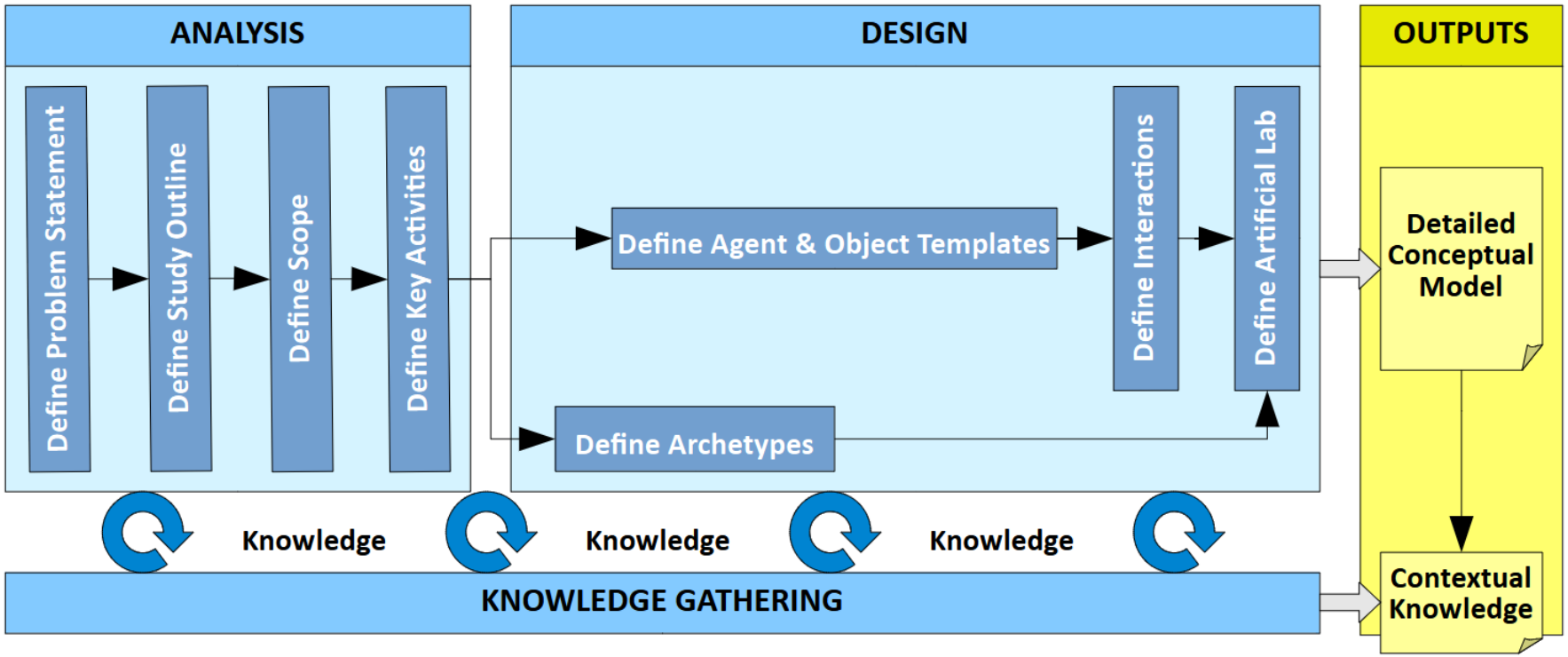


Play

Siebers et al (2018)

Conceptualising Agent-Based Models

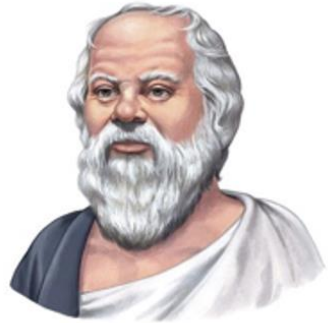
- The Engineering Agent-Based Social Simulation Framework



Adapted from Siebers and Klügl (2017)

The EABSS Framework

- Using mini focus groups
  - Group sizes of **4-5 participants** (including moderator) work best
  - Estimated time to get through the whole process: **4 hours** (or more)
  - Confucius vs Socrates
    - Collaborative (inclusive) brainstorming
    - Mainly discussions (information gathering)
    - Debates only when needed
  - Moderators (usually the modeller)
    - Will often also act as a stakeholder
    - Will guide the discussions
  - Iterative process
    - Reuse of information from previous steps
    - Important to go forward and backwards



Engineering Agent-Based Social Simulations

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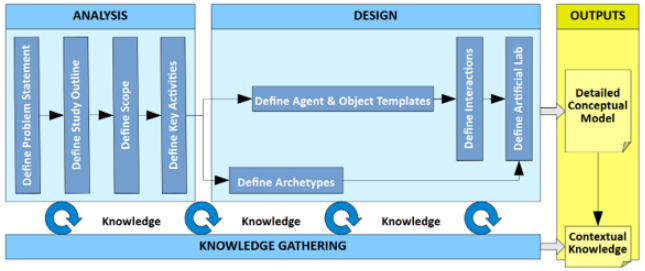
Brief Summary with Example Snippets

High level overview of the EABSS-2



Small print orange remarks are meant to guide the focus group moderator regarding the re-use of information; purple remarks list the tools to be used in that particular step.

Define Problem Statement (also clarify terminology and come up with a common pool of term definitions)

- Clarify the "Purpose" of the model, if not provided by the client:
  - Study title
  - Broad theme(s) (Blue Sky; Toy; Organisation Studies; Social Studies; Operations Research; Operations Management; Economics; Ecology; …)
  - Sub-theme(s) (Service Systems; Emergency Modelling; Organisational Cognition; Human/Natural Systems; Occupant behaviour; …)
  - Study approach (level of abstraction [strategic …]; purpose [exploratory …]; driver [theory …])
  - Study context (background information that provides a framework for understanding the research problem and its significance)
  - Study aim (a broad statement indicating the general purpose of your simulation study; consider title + themes + context)

Define Study Outline (also clarify terminology and come up with a common pool of term definitions)

- Define a list of "Objectives" (and constraints) to be fulfilled and/or "Hypotheses" to be tested (objectives: how you plan to achieve your aim; hypotheses: an attempt at explaining a phenomenon or the relationships between phenomena/variables in the real world)
- Define a list of "Experimental Factors" (parameters) to allow creating scenarios relevant to testing objectives and/or hypotheses (look at objectives/hypotheses to work these out)
- Define a list of "Responses" (outputs/statistics) for measuring if objectives have been achieved and to test if hypotheses should be accept/reject (look at objectives/hypotheses to work these out)

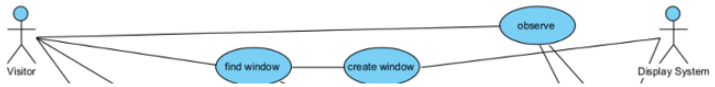
Define Scope (what do we need to represent to fulfil the aim; use "Context" words captured and "nouns" from the previous answers)

- List entities (key actors - represented by the role they play, and key objects) and concepts (key actors can also represent social/economic units, as for example families or firms)
- Indicate if these should be included/excluded in the model and justify your decision
- Use pre-defined table (COLUMNS: Category; Sub-Category; Element; Decision; Justification; CATEGORIES: Actor; Physical Environment; Social and Psychological Aspects; Misc)

Category	Sub-Category	ID	Element	Decision	Justification
Actor	Human	A01	Visitor	Include	Main research subject
		A02	Group	Include	Important for capturing group behaviour
		A03	Staff	Exclude	Have no impact on the dynamics
	Intelligent	A04	Content window	Include	Intelligent artefact that can make proactive decisions

Define Key Activities (actors come from scope table; key activities come from objectives/hypotheses and by creating user stories)

- Formulate user stories: As <actor>, I want to <what?> (so that <why?>)
- Assign key actors to relevant key activities (use cases)
- Use UML use case diagram



Define Archetypes (these allow to define behaviour of actors; units and values are not really required at this stage, but should be captured if they emerge from the discussion)

- Come up with categorisation schemata for relevant key actors (agents) that will allow to separate a simulated population into behaviourally different groups
- Use habit template(s) and/or demographics and/or utility function(s)

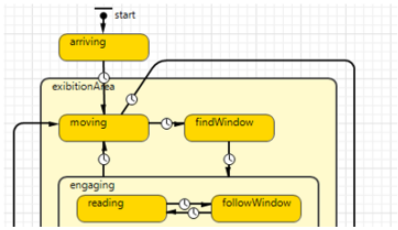
Visitor: Interest-related behaviour

Archetype	Reading time [seconds]
Disinterested visitor	3-10
Average visitor	10-40
Researcher	40-90

Define Agent & Object Templates (AGENT LEVEL) (state charts: states can often be derived from use cases; state variables are often a level of something, e.g. tiredness level; state transitions: transition start/end can be derived from state chart; agent & object classes: attributes can be derived from archetype criteria and by looking at the scope table; operations can be derived from the states in the related state charts)

- The following is done in parallel
  - Create state chart templates by defining key states an entity can be in and how these are linked
  - List State variables (dynamic variables representing entity states)
  - Create a table that defines triggers for transitions
  - Create classes (3 sections) providing a name, listing attributes, and listing activities and conditional checks
  - Use UML state machine diagram(s); transition table(s); class definition(s)/diagram(s)

Visitor: State chart

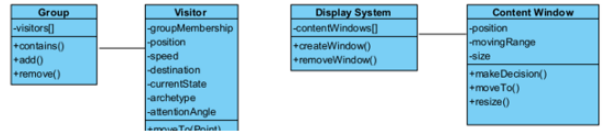


Visitor: State transitions

From State	To State	Trigger Type	Notes
arriving	moving	Timeout	Pseudo state; takes no time; adds transparency
moving	findWindow	Condition	Choose window
findWindow	engaging	Timeout	Pseudo state; takes no time; adds transparency
engaging/reading	engaging/followWindow	Timeout and Condition	Linked to archetype

Visitor: State variables: Location; mood; interest/fatigue/satisfaction level

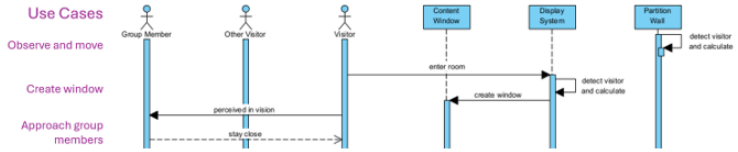
System: Classes and relationships



[] indicates a collection of elements
() indicates that we are dealing with an operation

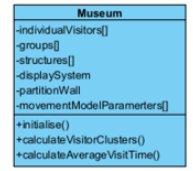
Define Interactions (SYSTEM LEVEL) (all elements defined in the Agent and Object Templates step need to be listed on the horizontal axis; use cases could be listed on the vertical axis; alternatively, a separate diagram could be created for each individual use case)

- Define sequences of interactions that can take place between agents and between agents and objects in specific use case realisations
- Use UML sequence diagram(s)



Define Artificial Lab (attributes provide storage for all agents and objects and initialisation parameters required for experimental factors; operations are related to responses; averages of agent and object dynamic variables could also be calculated)

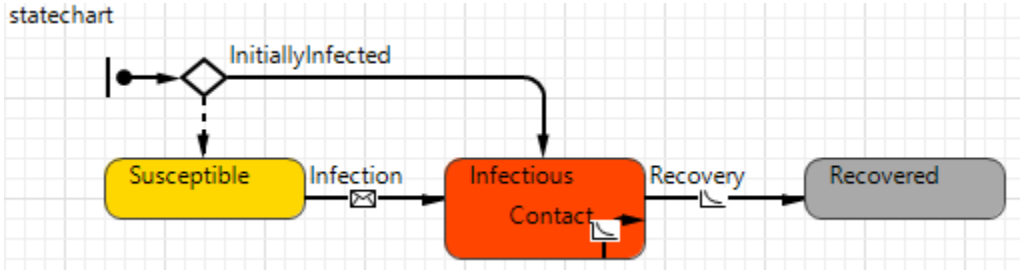
- List entities that need to be created; listing variables that ought to be tracked at the macro level to gain insight about the issues identified during the problem analysis
- Define order of execution (if relevant)
- Use UML class definition for capturing class content and sequence diagram(s) for capturing execution order

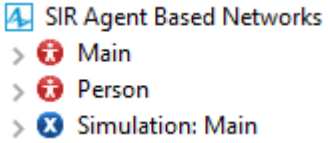


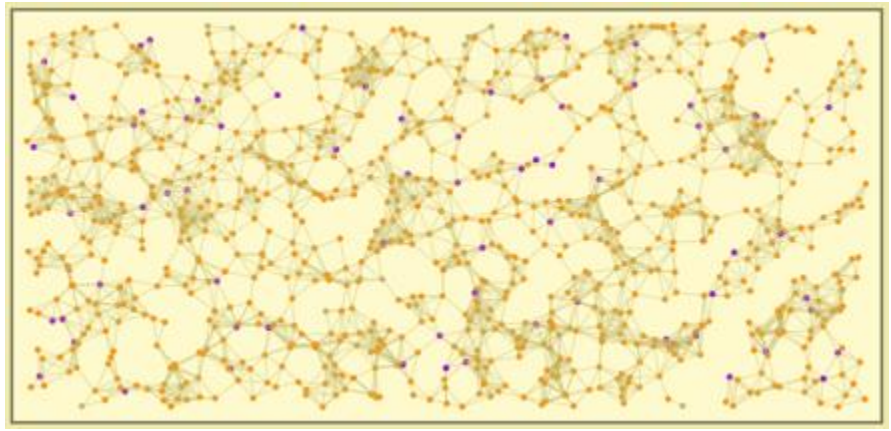
Siebers (2023)

Building and Validating Agent-Based Models

- Building an ABM (OR/MS)
  - Identify active entities (agents)
  - Define their states and behaviour
  - Put them in an environment
  - Establish connections
  - Test the model
- Validating an ABS
  - Validation at micro level
    - Testing the behaviour of agents at individual level
  - Validation at macro level
    - System behaviour is an emergent property
    - Plausibility check of emerging patterns at system level (e.g. via comparison to observations)



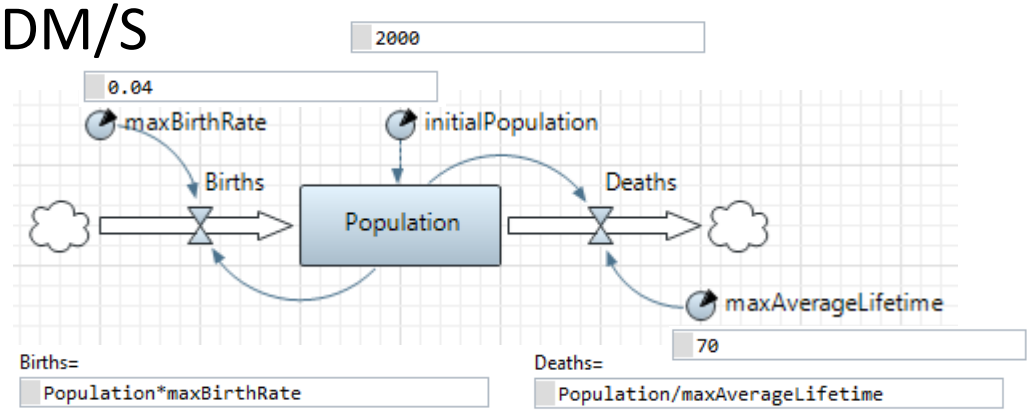




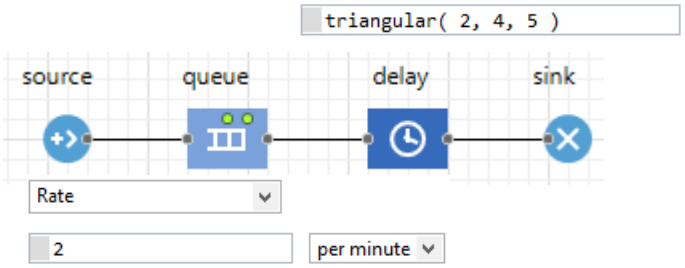
Source: AnyLogic Help

Examples for the Different Simulation Modelling Paradigms

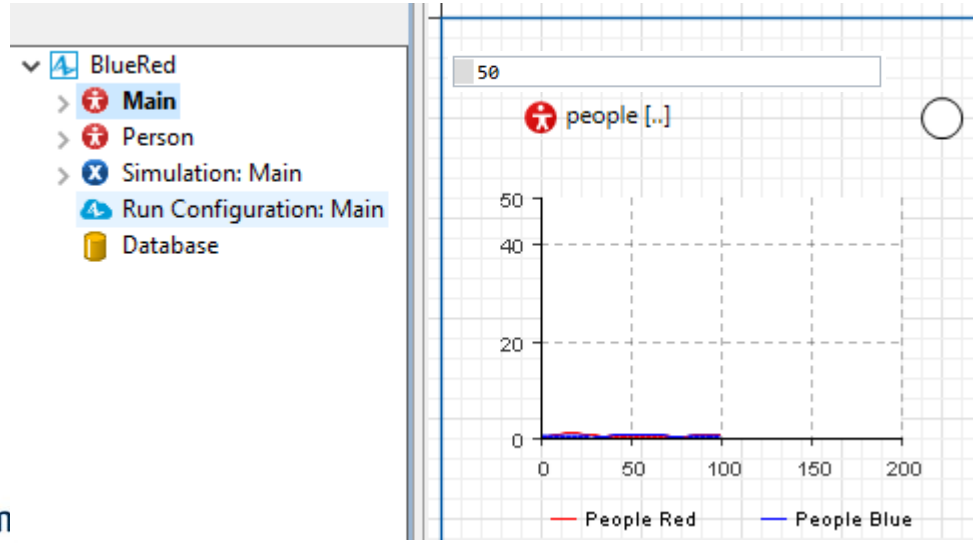
- SDM/S

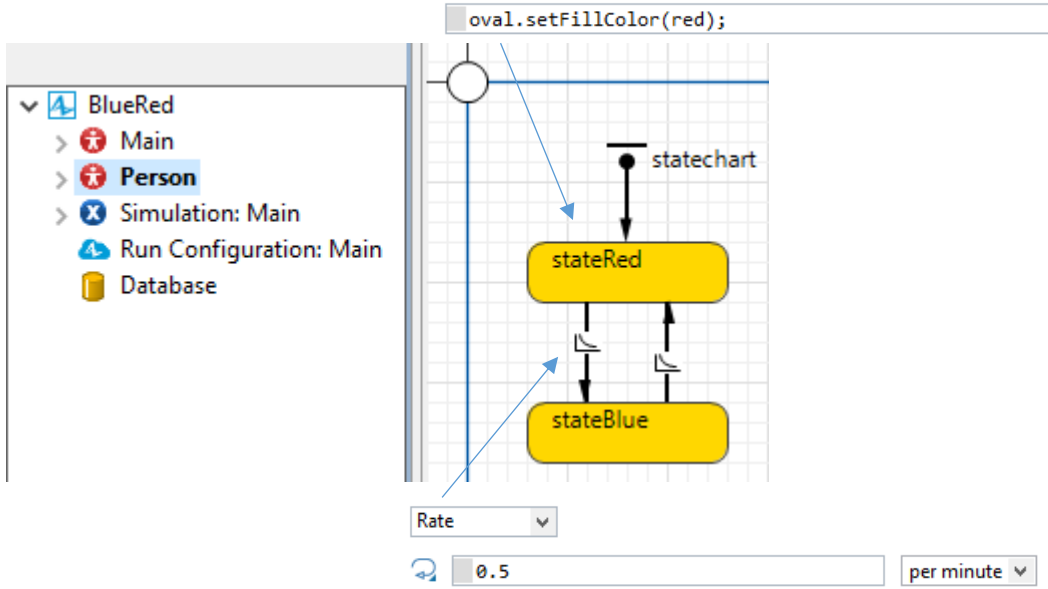


- DEM/S

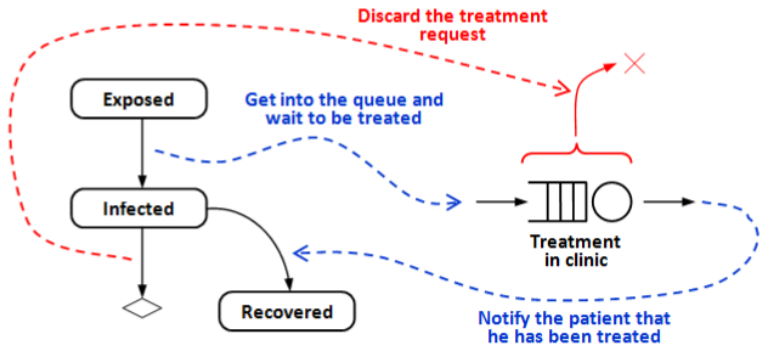


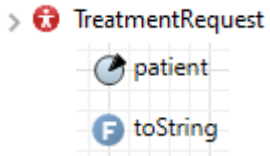
- ABM/S

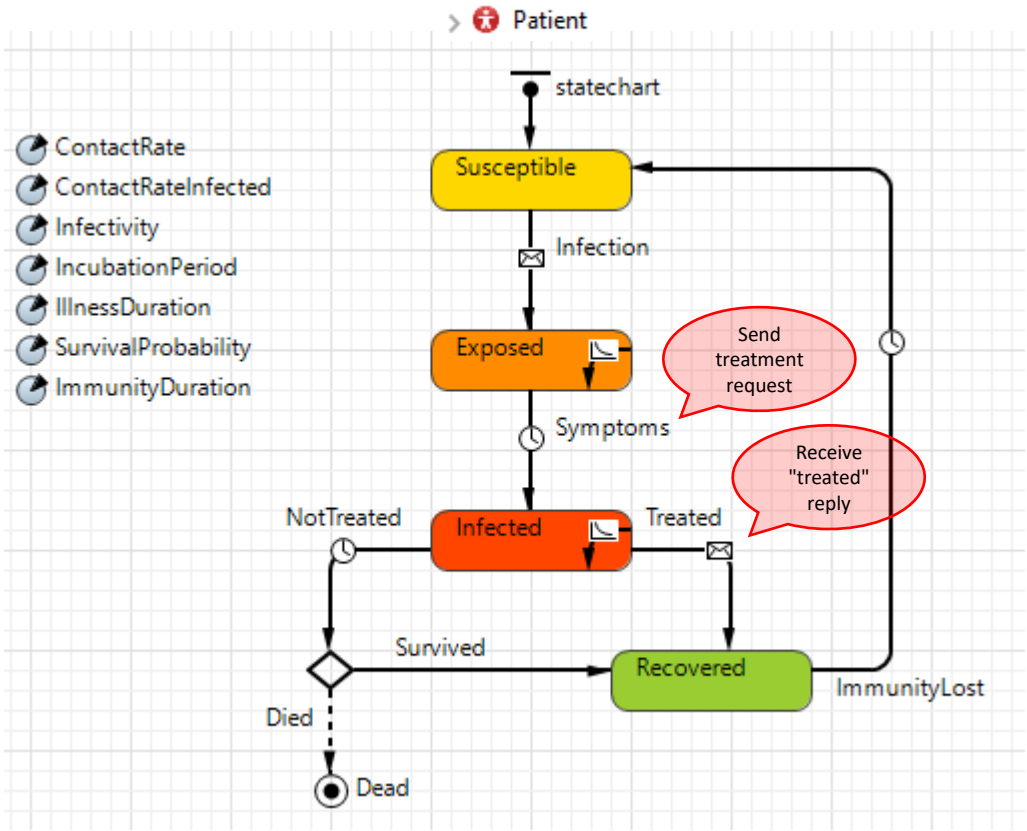


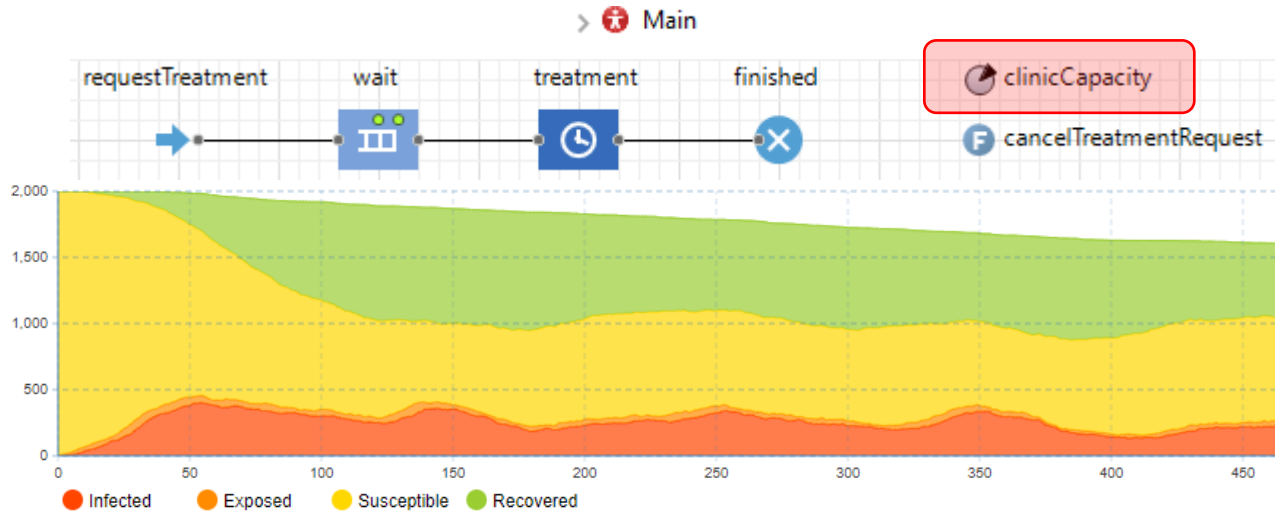


Multi-Paradigm Modelling







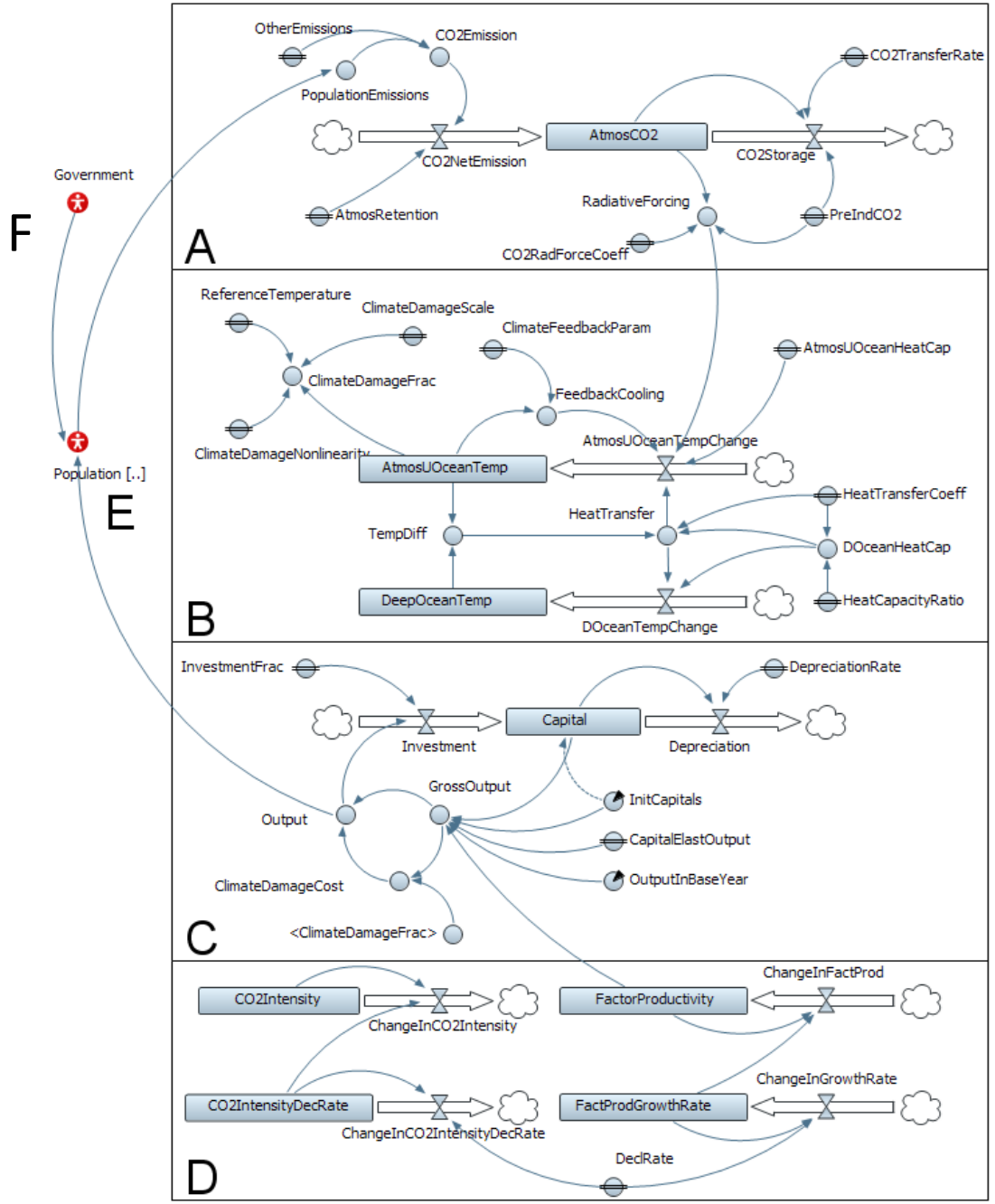


Source: AnyLogic Help

Multi-Paradigm Modelling

- Example
  - Multi-Method Integrated Assessment Modelling of Global Climate Change

- Base model
  - A = Carbon Cycle
  - B = Climate Subsystem
  - C = Economy Subsystem
  - D = Exogenous Drivers
  - E = Population
  - F = Government (Policy Makers)

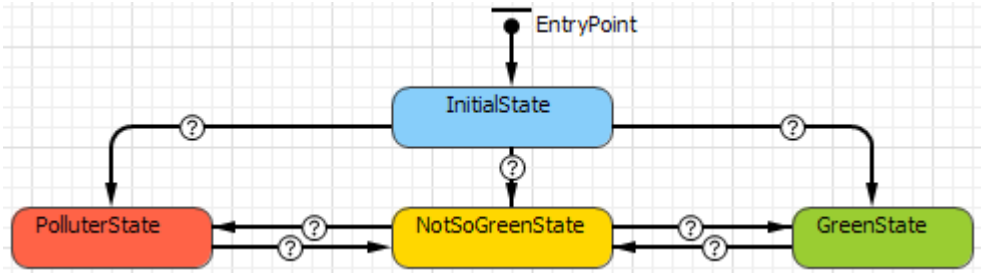


Siebers et al (2020)

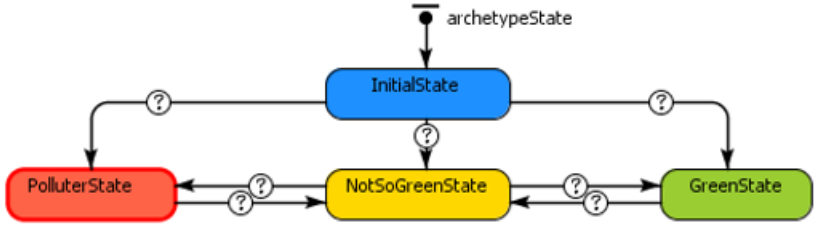
Scalability of Agent Representation

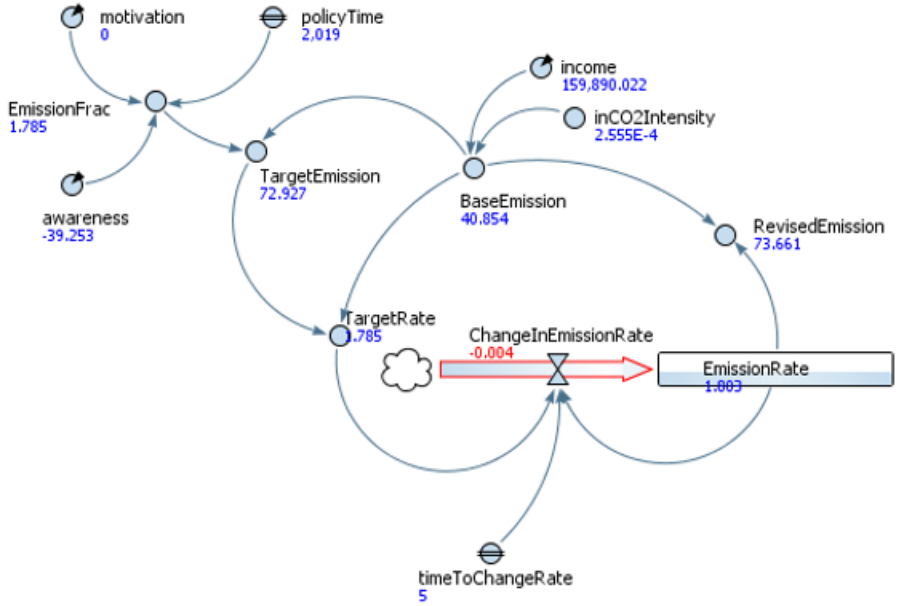
- Collective Person Agents (CPAs)
  - Capturing large populations through scaling (e.g. 1:250,000)
  - Activities of CPAs
    - Consume energy; produce emissions; network with other CPAs

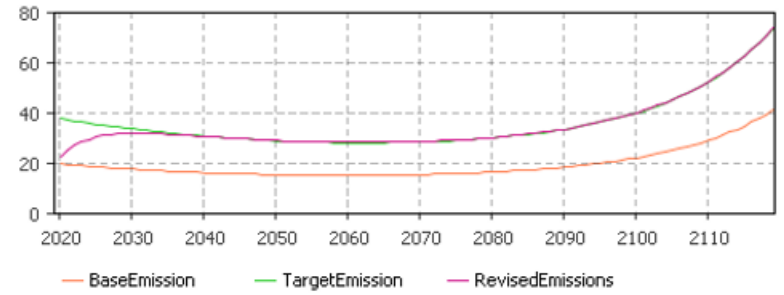
- Classifications of CPAs
  - They are classified into different stereotypes, based on their emission levels; these range from "green" to "polluter"

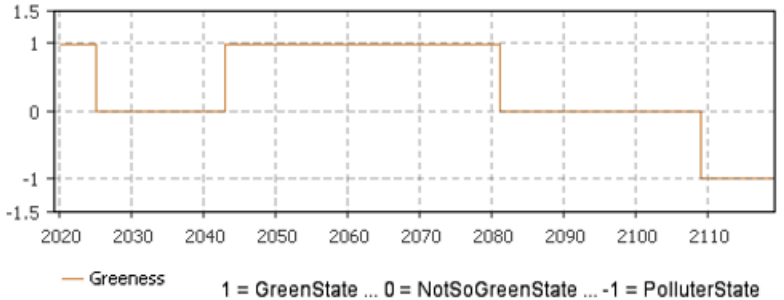


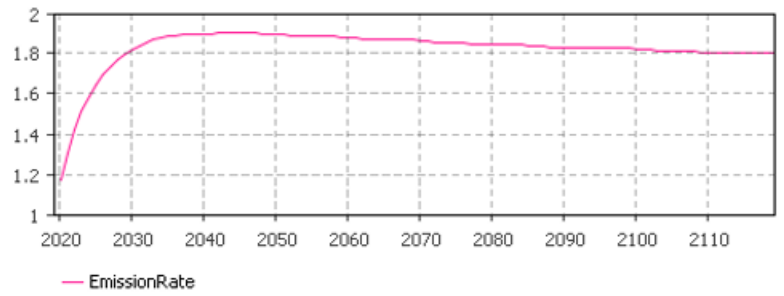
Collective Person Agent During Runtime





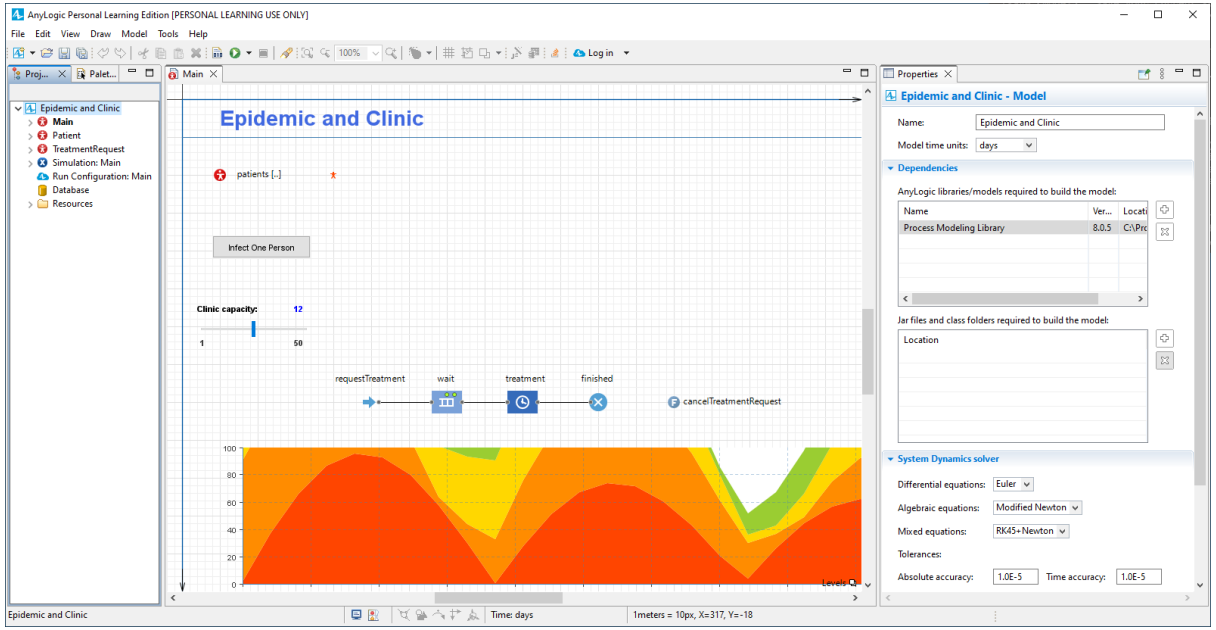






Software for Implementation

- AnyLogic PLE
  - Proprietary software with a free personal learner edition and free introductory eBook
    - https://www.anylogic.com/downloads/
    - https://www.anylogic.com/resources/books/free-simulation-book-and-modeling-tutorials/



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Questions / Comments

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