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Generative Agent-Based Social Simulations: Early Prototypes for Epidemiology and Energy Systems

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Agent-Based Modelling and Simulation

Agent-Based Modelling

- Agent-Based Modelling (ABM)
  - 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

- Agent-Based Social Simulation (ABSS)
  - Applies ABM specifically to social systems: modelling people, groups, institutions and their interactions
  - Examples:
    - Social Cohesion: How groups form and maintain bonds
    - Social Norms: Rules that emerge without central authority
    - Cultural Dynamics: Spread of beliefs and behaviours
    - Spatial Patterns: How people organise in physical space

Building Agent-Based Models

- Schematic representation of an agent-based model

  - Develop agent-based models
    - Define the problem
    - Identify active entities (agents)
    - Define their states and behaviour
    - Put them in an environment
    - Establish connections
    - Validate (bugs and plausibility)

Source: Ramadiah A, Galbiati M, & Soramäki K (2021). Agent-based simulation of central bank digital currencies. Available at SSRN 3959759.

Agent-Based Modelling Approaches

Source: Claude Sonnet 5 Medium

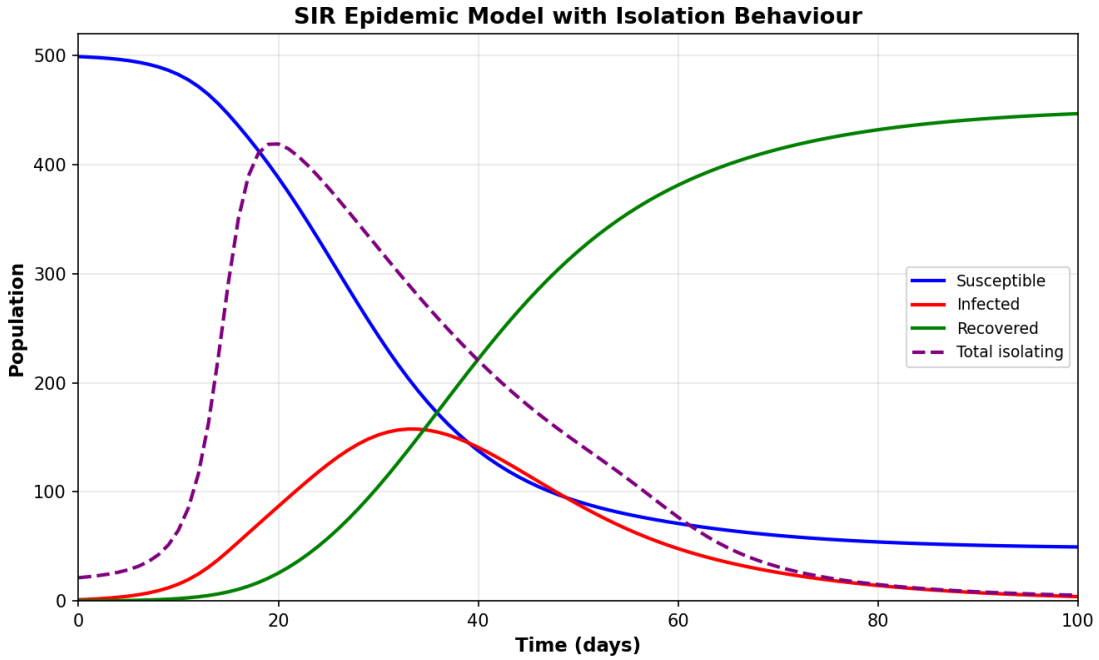
Feature	Typical Mathematical Epidemic ABM	Rule-Based Social Simulation ABM	Generative (LLM-driven) ABM
Primary Focus	Predicting numerical disease trajectories (cases, hospitalisations)	Understanding emergent social patterns from prescribed behavioral rules	Exploring open-ended, nuanced social interactions, narratives, and strategic deception
Decision-Making Mechanism	Probabilistic transitions (e.g., draw a random number to transition S→I based on a fixed transmission rate)	Explicit symbolic (if-then) rules or finite state machines, where agents transition between predefined behavioural states based on triggering conditions.	Generative inference (e.g., LLM reads agent's persona, memory, and context, then generates a free-text action/reasoning chain)
Human Behavior	Simplified to epidemiological parameters (e.g., contact matrices, viral shedding)	Heterogeneous, but confined to the pre-scripted logic the programmer wrote	Highly nuanced, socio-emotional, and context-aware; can display empathy, sarcasm, or irrational fear based on rich memory
Emergent Phenomena	The epidemic curve (R0, herd immunity thresholds)	Macro-level adherence patterns (e.g., polarisation of mask-wearing)	Emergent narratives, cultural drifts, unplanned alliances, and "theory of mind" cascades
Modelling Approach	Bottom-up implementation of a top-down mathematical system	Purely bottom-up, where macro patterns emerge from micro explicit rules	Purely bottom-up, where macro patterns emerge from micro latent reasoning in a neural network
Transparency / Reproducibility	High: fully transparent equations, perfectly reproducible	High: logic is visible in the code; deterministic if seeded	Low: the "logic" is a black box; outputs are stochastic, highly sensitive to prompts, and rarely reproduce exactly
Computational Cost	Very low	Low to medium	Extremely high (requires GPU clusters for hundreds of agents)

Epidemiology (G)ABM Example

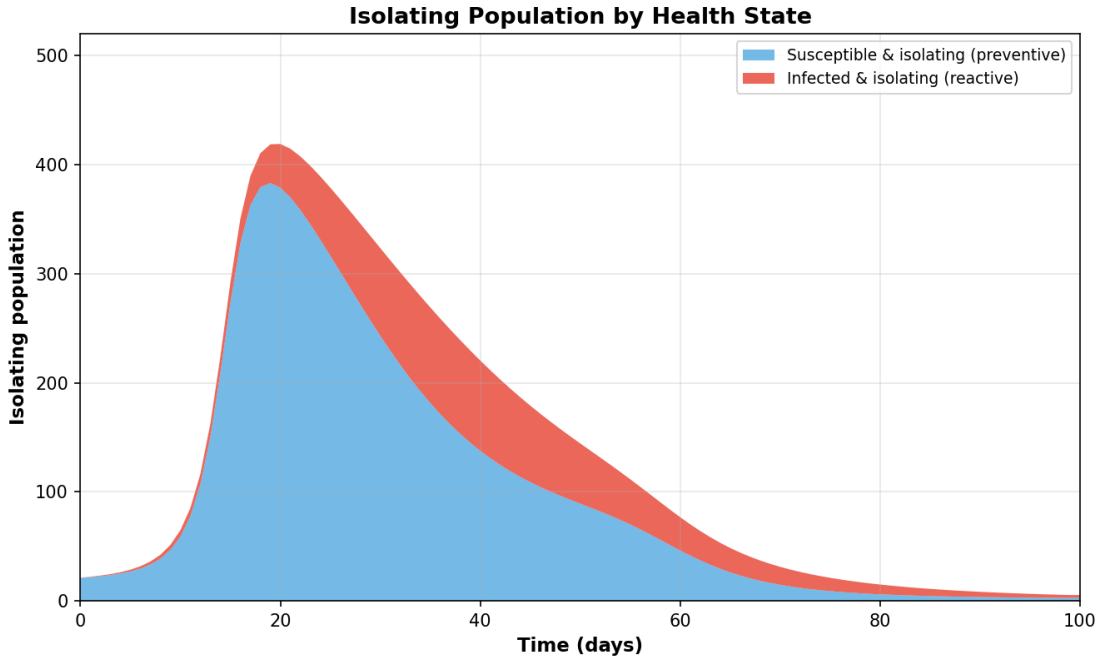
Isolation Decisions during Pandemic

Isolation Decision during Pandemic

Expected Outcome

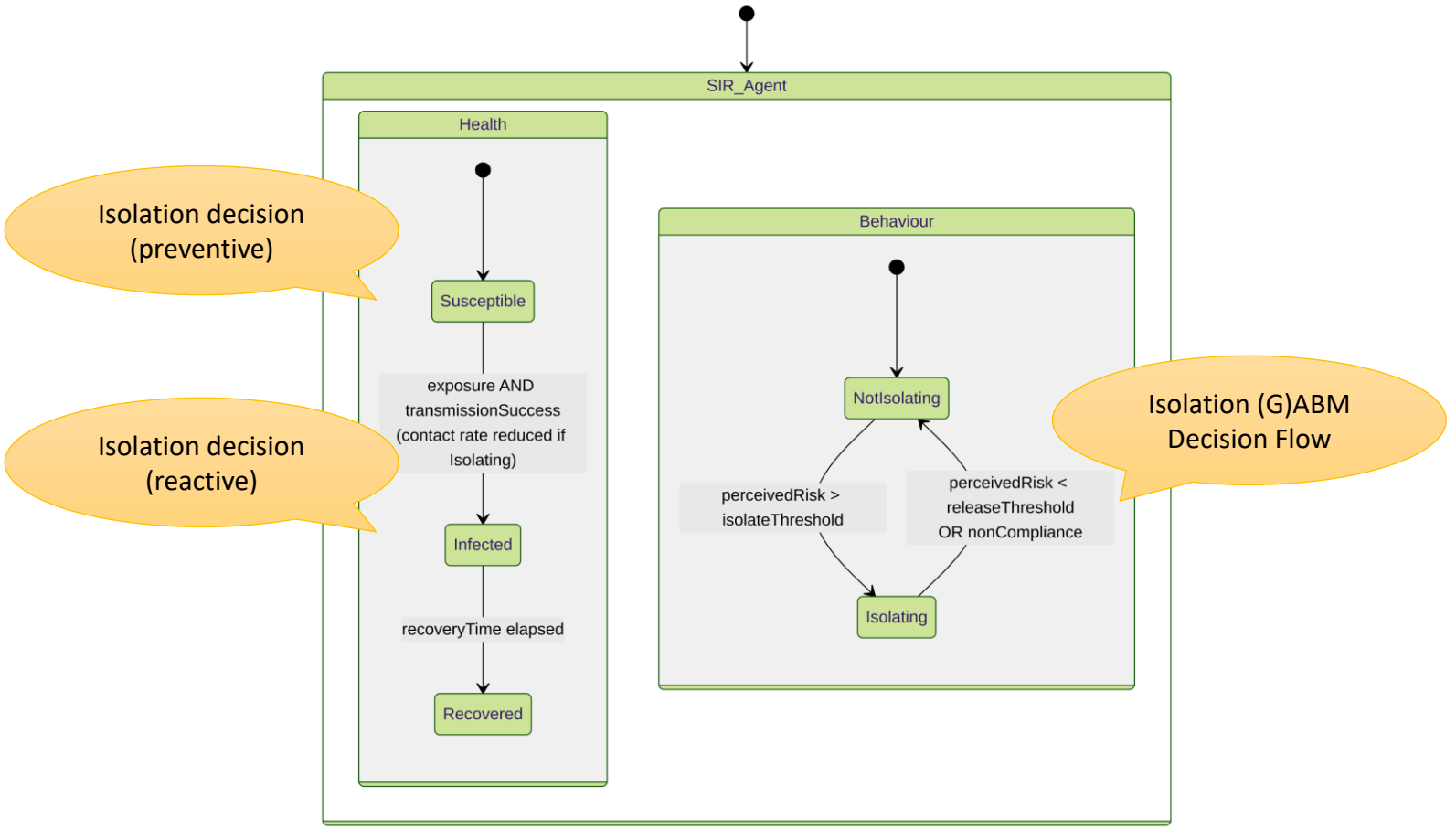


Compartmental model curve



Stacked area chart

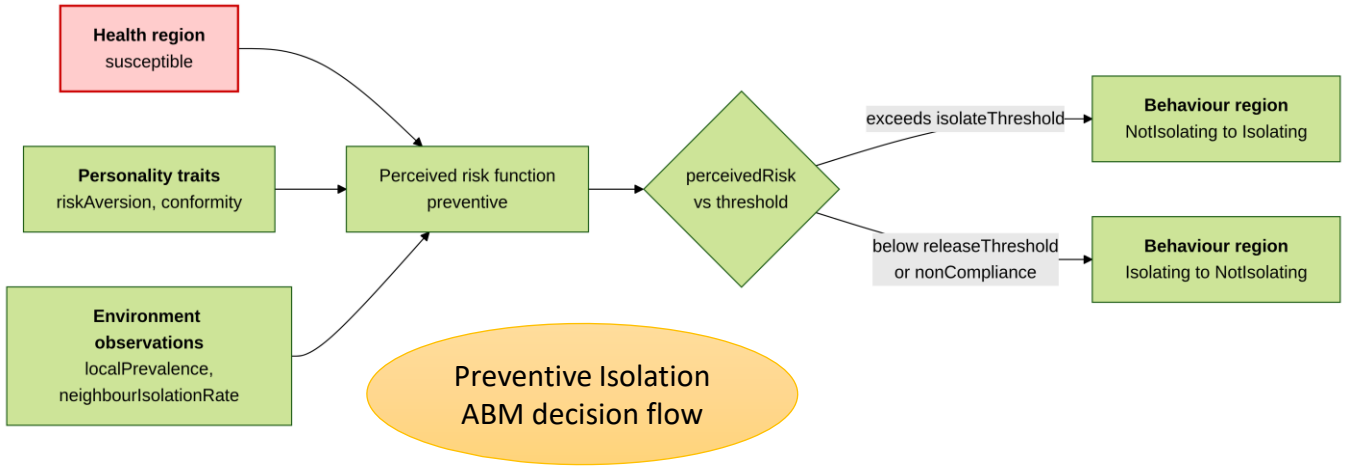
SIR Agent State Chart

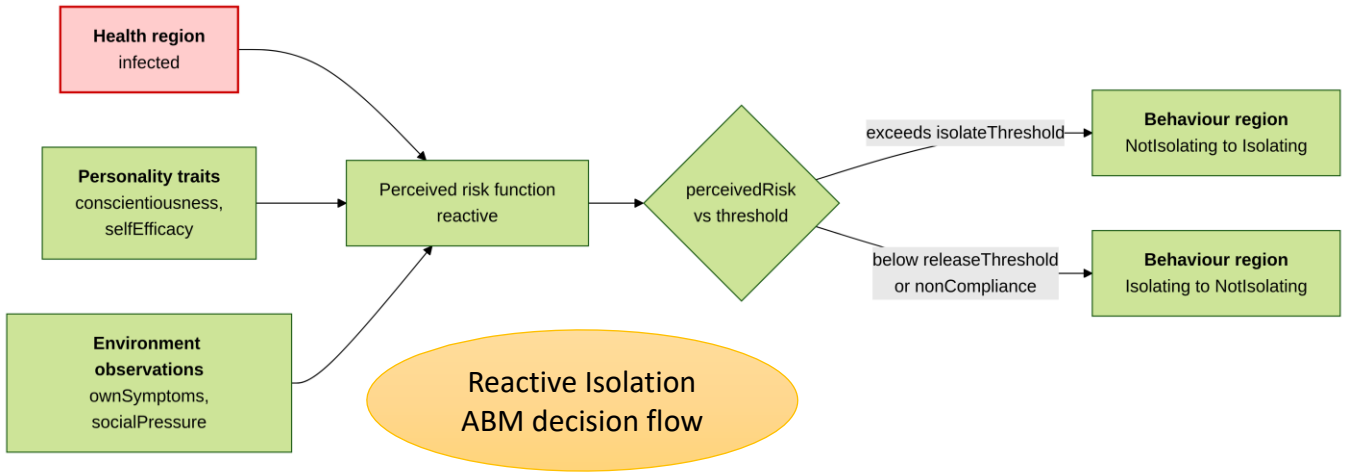


State
Transition
Branch
Final State
Initial State Pointer
History State

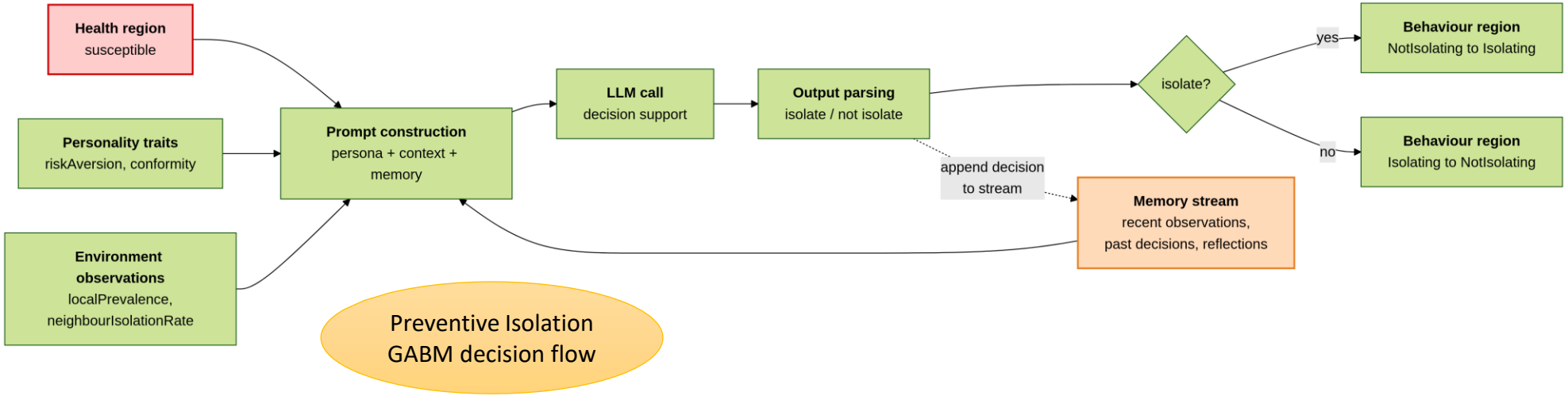
Transition triggered by
- Timeout
- Rate
- Condition
- Message

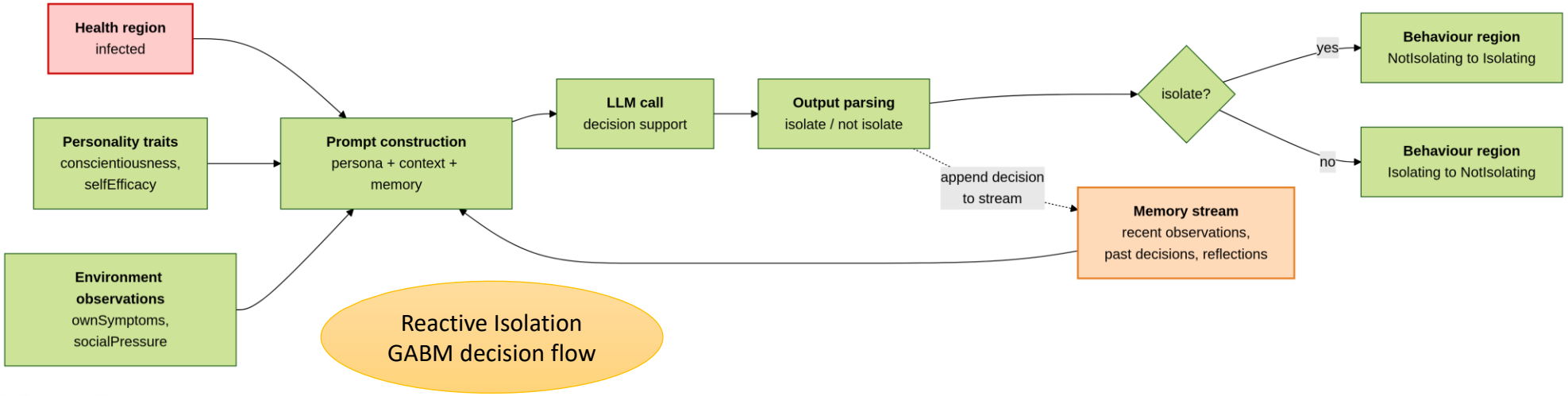
SIR Agent ABM Decision Flow





SIR Agent GABM Decision Flow





GABM Conversation

- Prompts
  - System: Rules to obey when generating responses
  - Main: Persona; context (goals and social interaction); memory
  - Validation: Assessment of previous response

Response
  - Decision: Yes/No
  - Reason: …

Input: {"messages": [{"role": "system", "content": "You are participating in a public-health simulation as a single, distinct individual within a community. You will be given a persona and a specific situation, and must decide how that individual would realistically act. Reply with a single, valid JSON object only, on one line, with no markdown code fences, no indentation or line breaks, and no text before or after it. Keep your stated reason concise, specific to the situation given, and consistent with the persona provided."}, {"role": "user", "content": "Persona: Elderly with health concerns, very cautious\n\nDay 1. Local trend (recent days): no established trend yet. Regionally: regional cases falling (prevalence 0.09%).\nNearby right now: 1 people, 1 infected (100% of the people near you are infected right now, a very high local density), 0 vaccinated.\n\nYour recent decisions:\n- Yesterday: decided ISOLATE (0/1 nearby infected). Reason: \"With my health concerns and even though nearby risks seem low, I'll avoid unnecessary exposure until more is known about how this spreads—better safe than sorry.\"\n\nShould you isolate today? Stay logically consistent with your persona\nand your own previous decisions above, unless you explicitly state what\nchanged your mind.\n\nRespond ONLY in this JSON format, with no extra text before or after it, and no schema symbols such as \"|\" or \"<...>\" in your answer. The example below shows the format only, not the expected answer; replace every value with your own genuine decision (YES or NO), a confidence between 0 and 1, and a brief single-sentence reason for your decision. Do not reuse the example's wording, its reason is a placeholder, not a suggestion:\n{\"decision\": \"NO\", \"confidence\": 0.7, \"reason\": \"One sentence, in your own words, explaining today's decision.\"}\n\nYour JSON answer:"}], "max_tokens": 512, "temperature": 0.15, "top_p": 0.9, "rep_pen": 1.1, "stop": ["###", "}"]}

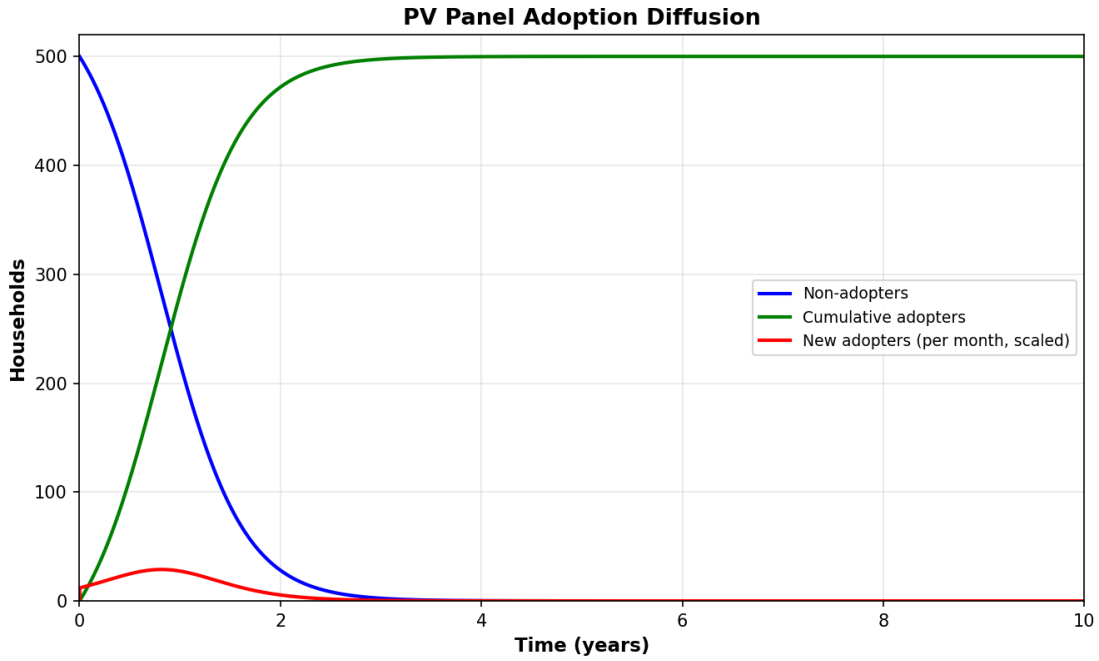
Output: {"decision":"ISOLATE","confidence":1,"reason":"The person nearby is infected and my compromised health means any risk is unacceptable—I won't take chances when my safety depends on absolute avoidance."

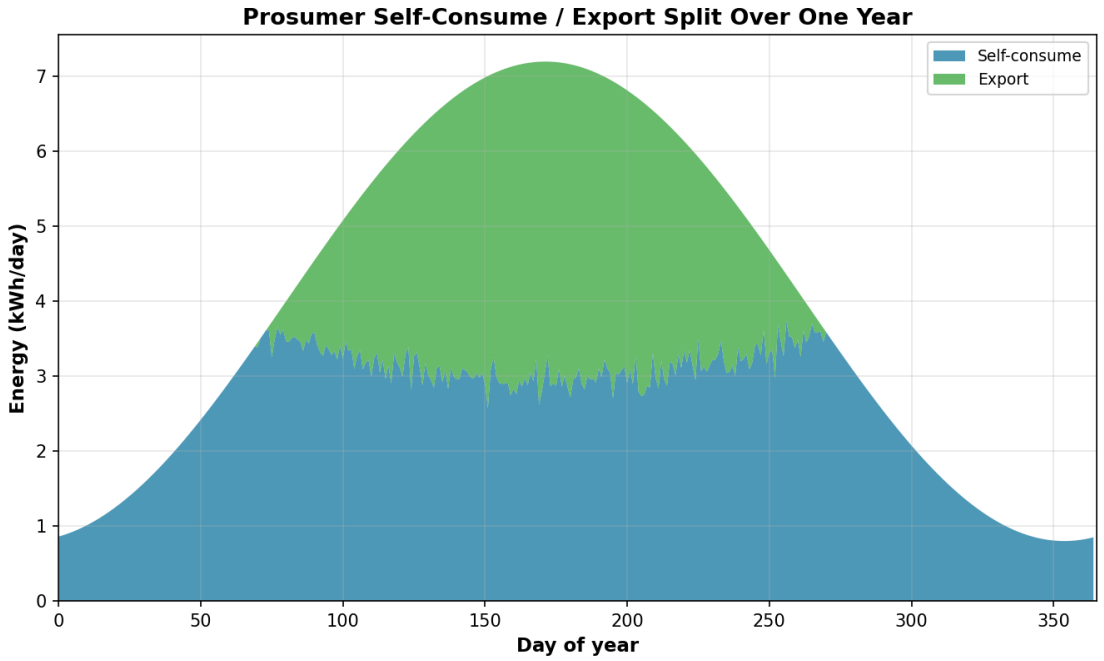
Energy Systems (G)ABM Example

PV Panel Adoption and Prosumer Behaviour

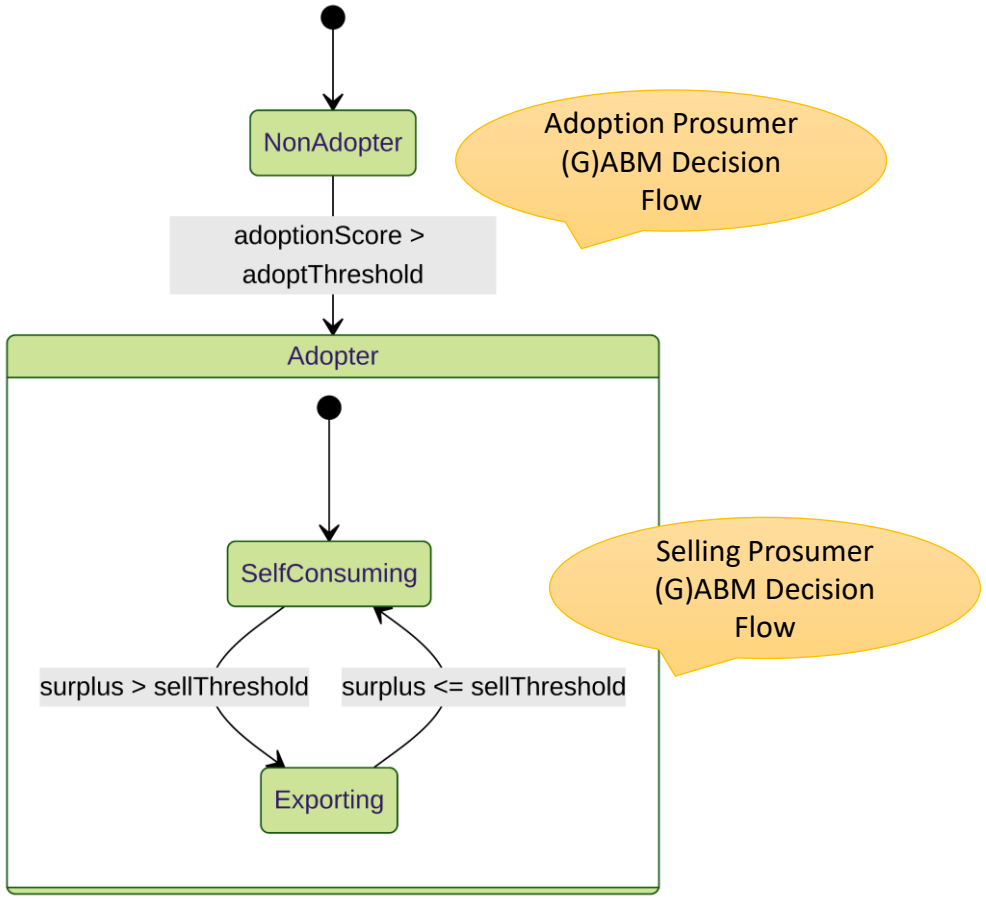
PV Panel Adoption and Prosumer Behaviour

Expected Outcome

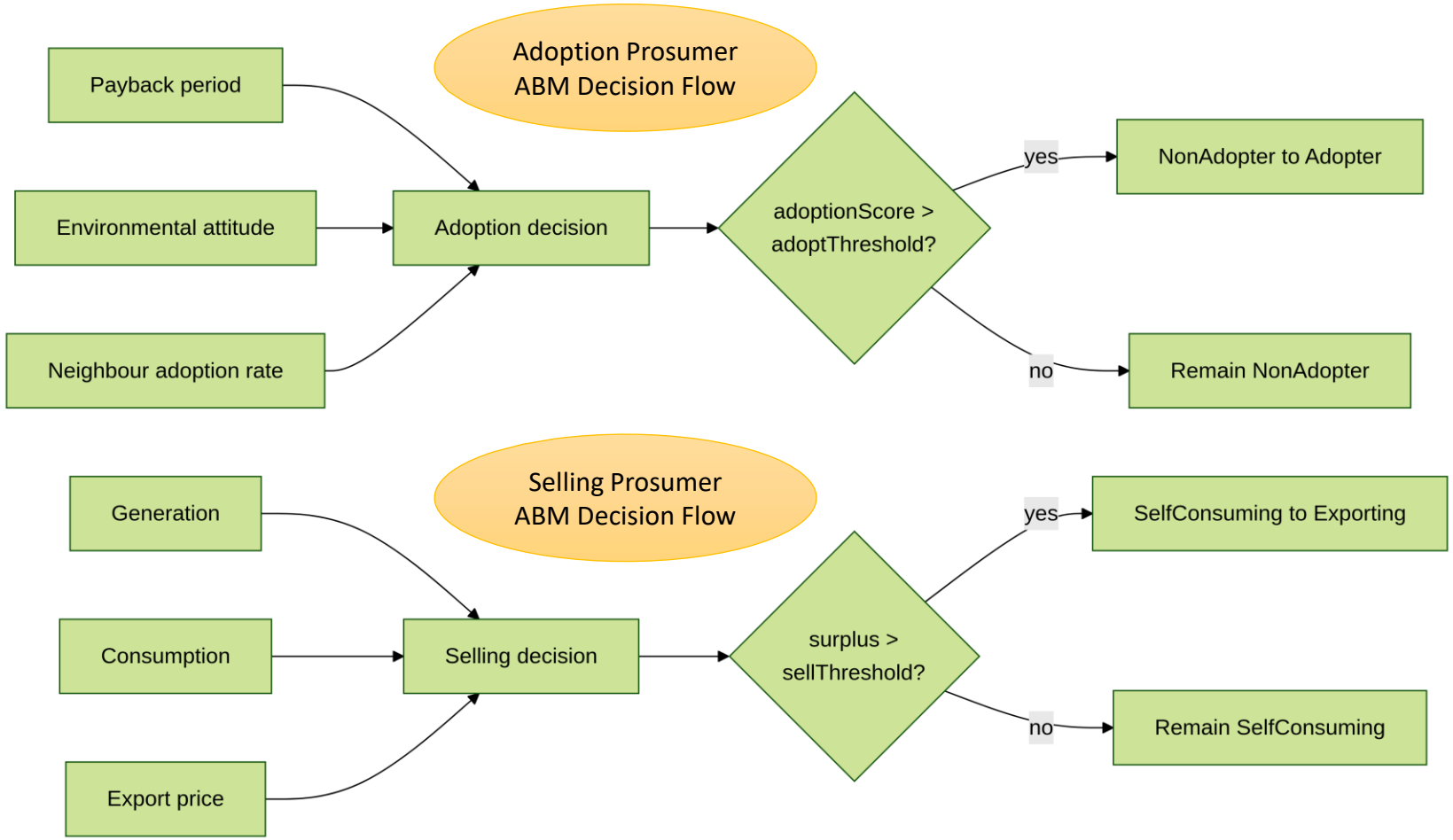




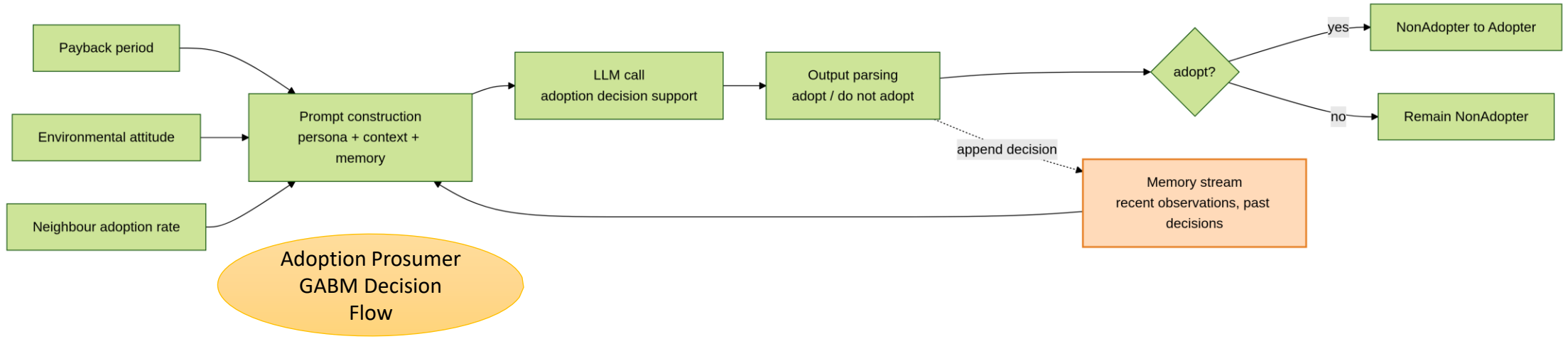
Prosumer State Chart

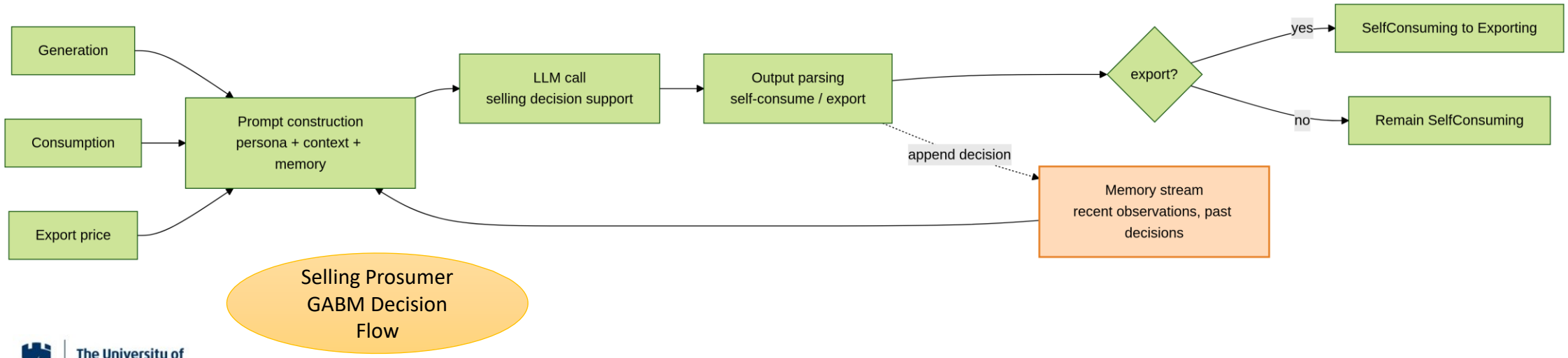


Prosumer ABM Decision Flow



Prosumer GABM Decision Flow





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Response
  - Decision: Yes/No
  - Reason: …

Input: {"messages": [{"role": "system", "content": "You are role-playing as a householder in a research simulation of residential solar PV adoption. Each turn you will be given a persona, your current circumstances, and a decision to make; fully adopt that persona's values and voice. Base your decision only on the facts given in the prompt; never invent figures that were not provided. Stay consistent with your persona and with your own past decisions shown in your recent-decisions history. This is a behavioural-science simulation, not real financial advice, so always give a decision rather than declining to answer. confidence (0-1) should reflect how strongly your persona feels about this decision given the information provided, not how certain you are that the numbers are correct."}, {"role": "user", "content": "Persona: Tech-savvy early adopter, enjoys new technology\nIncome: $109134, environmental attitude: 0.46 (0=low,1=high)\nDay 1. Your neighbours: 0/15 have adopted PV.\nEstimated annual savings: $607, payback period: 11.3 years.\nYour recent decisions:\nNothing recent stands out in your memory.\nShould you adopt PV today?\nRespond with a single JSON object only — no markdown fences, no text before or after it.\nValid values for \"decision\": ADOPT, WAIT, REFUSE.\nExample:\n{\"decision\": \"WAIT\", \"confidence\": 0.7, \"reason\": \"Still unsure about the cost.\"}\nYour answer:"}], "max_tokens": 256, "temperature": 0.2, "top_p": 0.9, "rep_pen": 1.1, "stop": ["###", "}"]}

Output: ```json

{

  "decision": "ADOPT",

  "confidence": 0.8,

  "reason": "Payback period of just over a decade aligns well with my tech-forward mindset—this isn’t just energy efficiency, it’s cutting-edge infrastructure. Early adoption excites me, especially since neighbors haven’t jumped on board yet. The savings feel meaningful, and I’d love to be part of the shift toward smarter homes."

GABM Experimentation and Output Analysis

- What kind of experiments can we run?
  - Sensitivity Analysis (vary experimental setting such as temperature; persona proportions; etc)
  - Testing impact of new policies (by adapting the prompts)
  - Prompt validation experiments
  - WHAT ELSE?

- What can we do with the qualitative output data?
  - Examine the decision-making and reasoning patterns of individuals over time
  - Understand the reasons behind changing trends
  - See if expected patterns emerge without predefined rules
  - WHAT ELSE?

Computational Scalability

- Use hybrid solutions
  - Link discretised mathematical models with ABM
  - Link discretised mathematical models with GABM
  - Link discretised mathematical models with ABM and GABM
  - Link ABM with GABM

- What information needs to be exchanged?
  - Epidemic model
    - Population-based pandemic status. WHAT ELSE?
  - Energy Systems model
    - Market dynamics data. WHAT ELSE?

Any Questions?

Resources

- Navid Ghaffarzadegan
  - Google Scholar: https://scholar.google.com/citations?user=rwKMpvIAAAAJ
  - Ghaffarzadegan, N., Majumdar, A., Williams, R., & Hosseinichimeh, N. (2024). Generative agent-based modeling: an introduction and tutorial. System Dynamics Review, 40(1), e1761.
    - https://onlinelibrary.wiley.com/doi/pdf/10.1002/sdr.1761