ETSI The Standards People

IoT Conference 2023

Combining Digital Twins with Cognitive Agents and Plausible Reasoning

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European Research Consortium for Informatics and Mathematics
ERCIM

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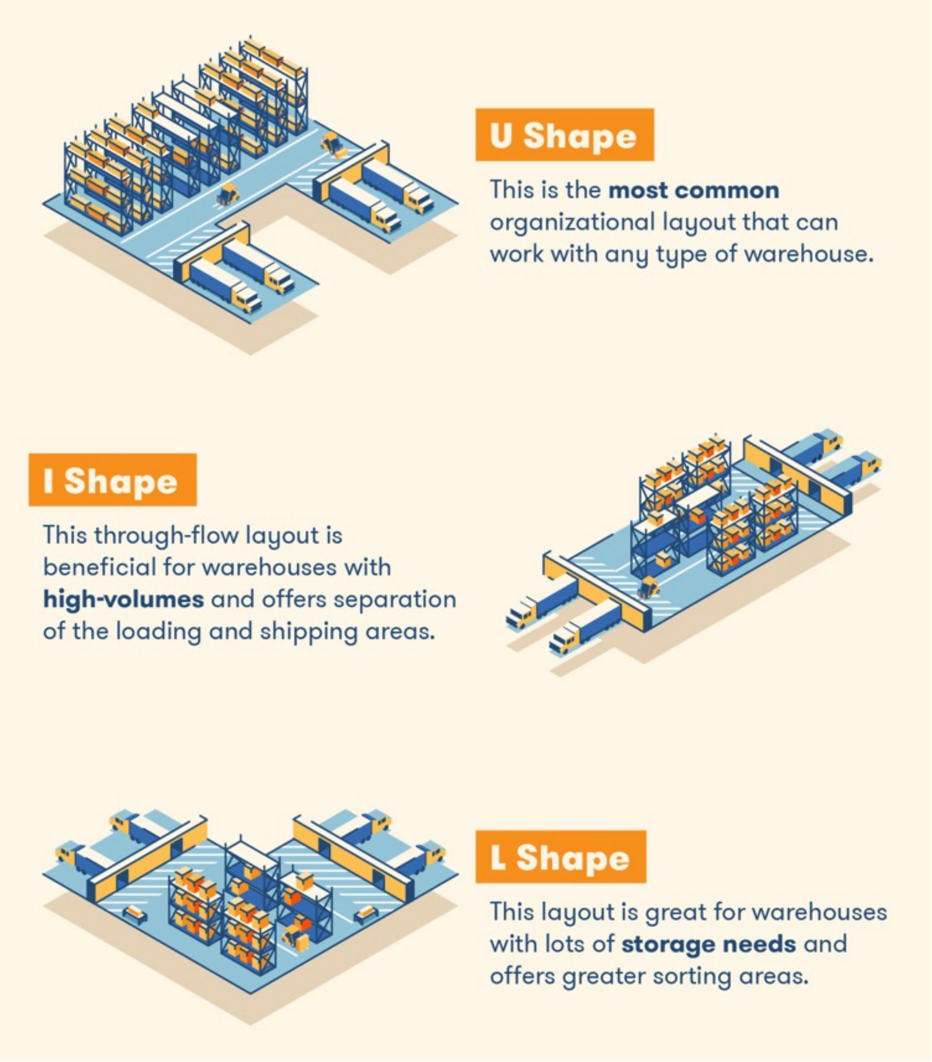
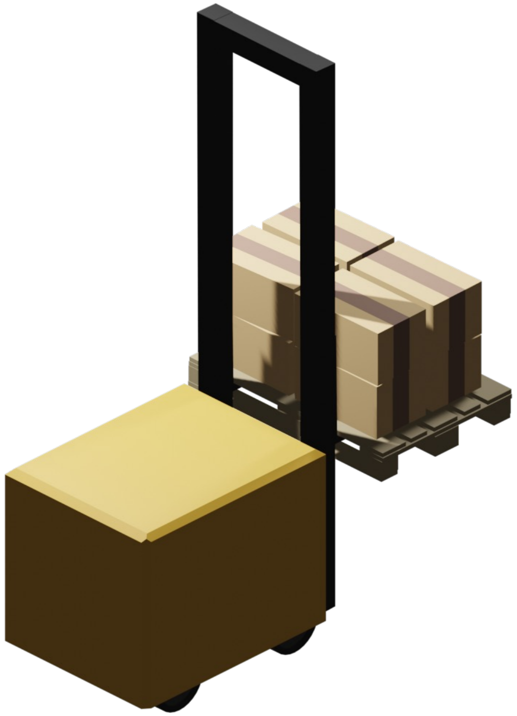
Designing Efficient Warehouses



Courtesy of [BIGrentz]

- How many docking bays, and where should they be situated?
- How many storage racks and what floor layout?
- How tall should the racks be?
  - Tall racks require specialised machines
- Picking and placing requirements?
  - Customised pallet loads
  - Use of conveyor belts?
- How many forklifts are needed?
- How to avoid forklift traffic jams?
- How many charging points and where should they be located?

SimSwarm: Simulating Multi-Agent Systems



- Swarms are a valuable approach to modelling collections of IoT systems at an abstraction level above that of digital twins.
- Simulations provide a low cost way to explore different algorithms in advance of real-world deployment.
- Cognitive models for low-code development.

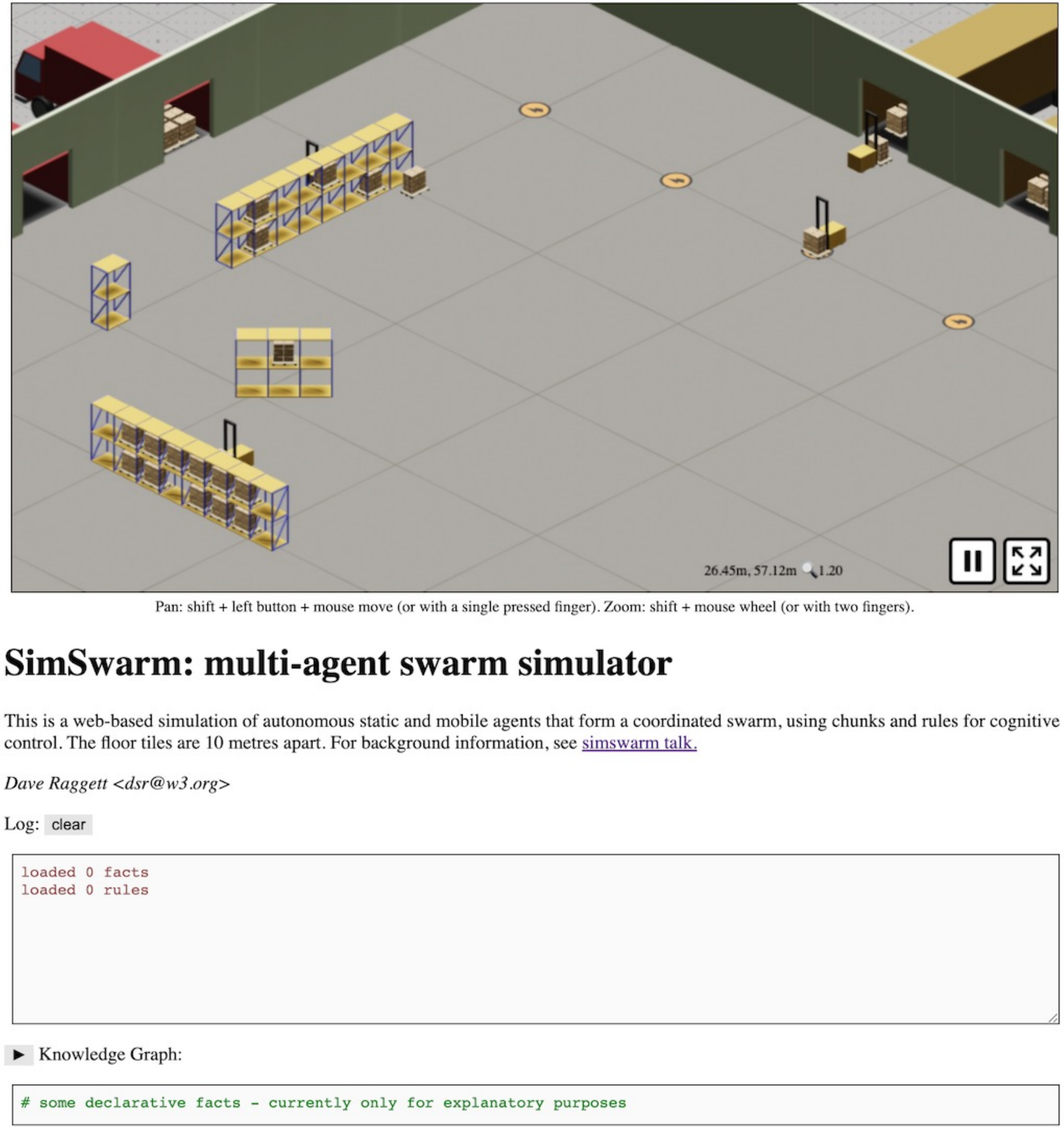
Distribution Warehouse as initial use case

- Swarm of robot forklifts that shift pallets between incoming trucks, storage racks and outgoing trucks
- Based upon message passing between autonomous agents
- Forklifts execute simple plans, plus collision avoidance rules
- Cognitive control to fulfil overall goals for timely and efficient distribution of goods

- 2.5D graphics using isometric game projection
  - 3D models created using Blender + python scripts to export image tiles
  - Rendered on HTML5 <CANVAS>
- Chunks & Rules JS engine
  - W3C Cognitive AI CG, and inspired by John Anderson's ACT-R (@CMU)
- Route planning and traffic management

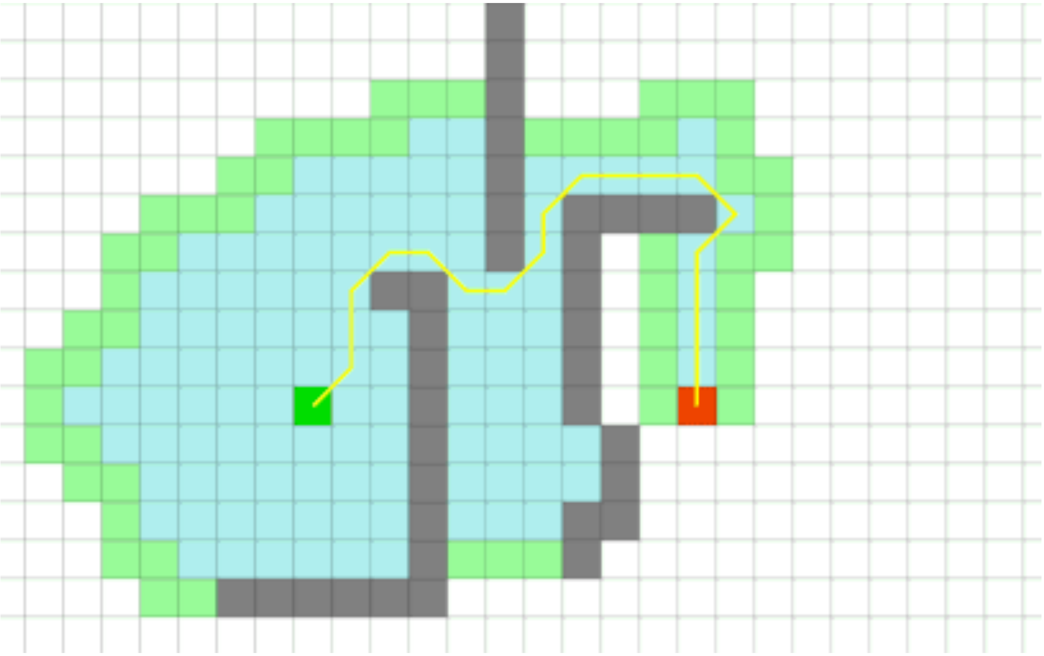
SimSwarm: web based isometric swarm simulator

- Multi-agent system
  - Autonomous mobile & static agents that communicate by exchanging messages
- Swarms can be smarter than their components
  - Emergent behaviour
  - Ant colony metaphor
- Smart agents using cognitive control
  - Flexible low-code framework using cognitive rules that operate on knowledge graphs
  - Local or cloud based
- Other agents using hard-coded behaviour
- User interface for high-level monitoring and control



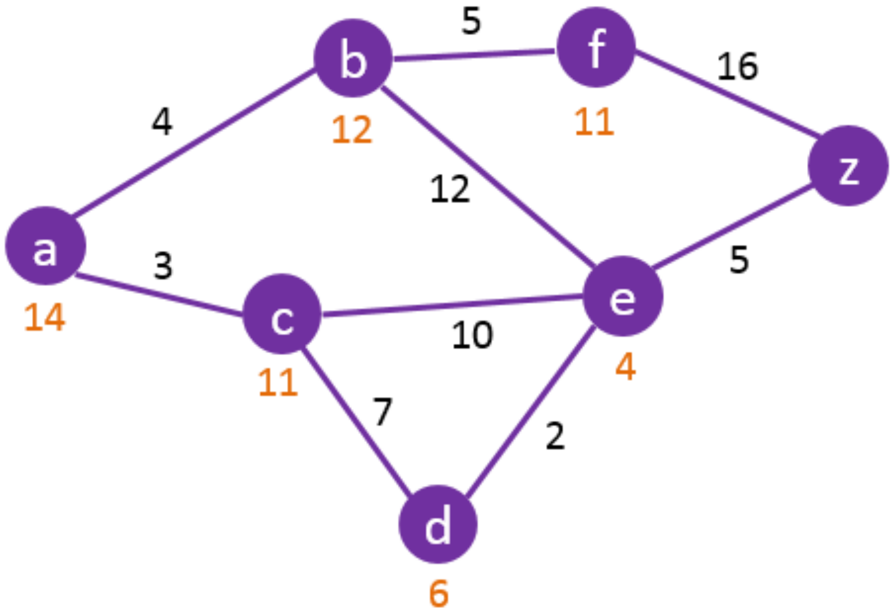
See: https://www.w3.org/Data/demos/chunks/warehouse/

Route Planning



Flood fill algorithm: annotates each cell with minimum distance from the start node.
Figure source: Wikipedia (license)

Grid-based algorithms

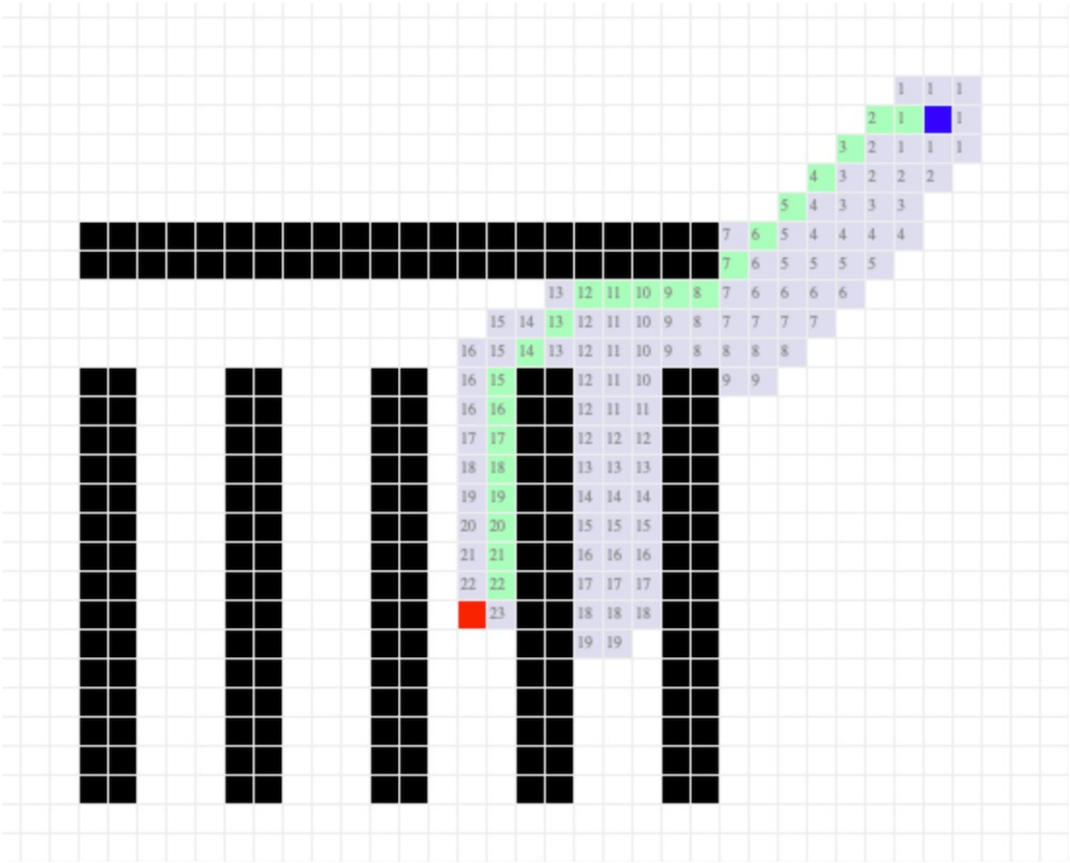


A-star algorithm: beam-search from start node to destination node, where orange numbers are distance as a crow flies from node Z and black numbers are direct distances between nodes.

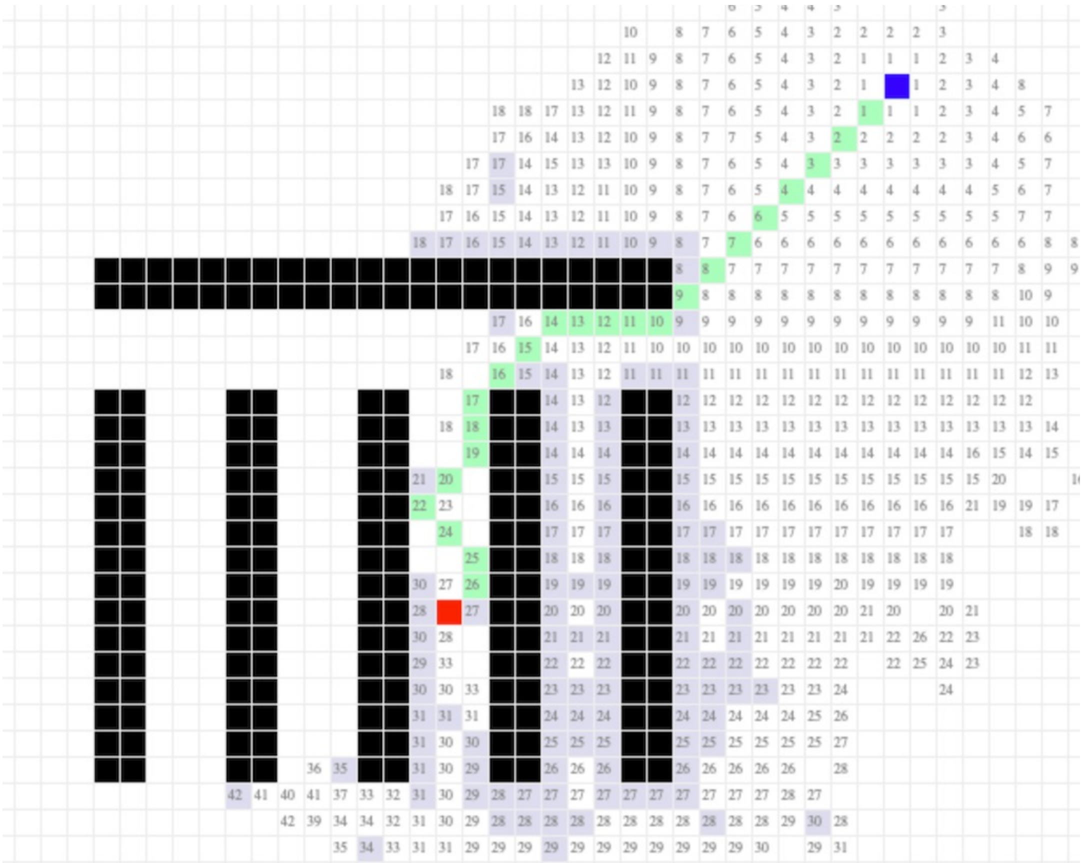
Graph-based Algorithms

Routing Algorithms

Ask me for a demo in one of the breaks



[A-star]



[Ant Swarm]

Route Planning and Traffic Management

- Simple grid-based algorithms such as A-star and Ant swarms are essentially blind
  - Feeling their way to the destination
- Humans have more sophisticated spatial and behavioural awareness
- Hierarchical classifications
  - e.g. districts, squares, roads and different kinds of junctions
- Lots of behavioural rules
  - e.g. when to give way to others
  - Fixed rules *vs* behavioural norms

- Traffic management
  - Gathering data
  - Ad hoc routing – no restrictions
  - Restricted routing – designated paths
- Optimal routing emerging from collective behaviour
  - Balancing distance travelled and delays due to collision avoidance, akin to human streams in busy crowds
  - Learning behavioural norms from interactions with other agents
  - Emergence of one-way lanes and traffic junctions

Cognitive Control
using rules + knowledge graphs

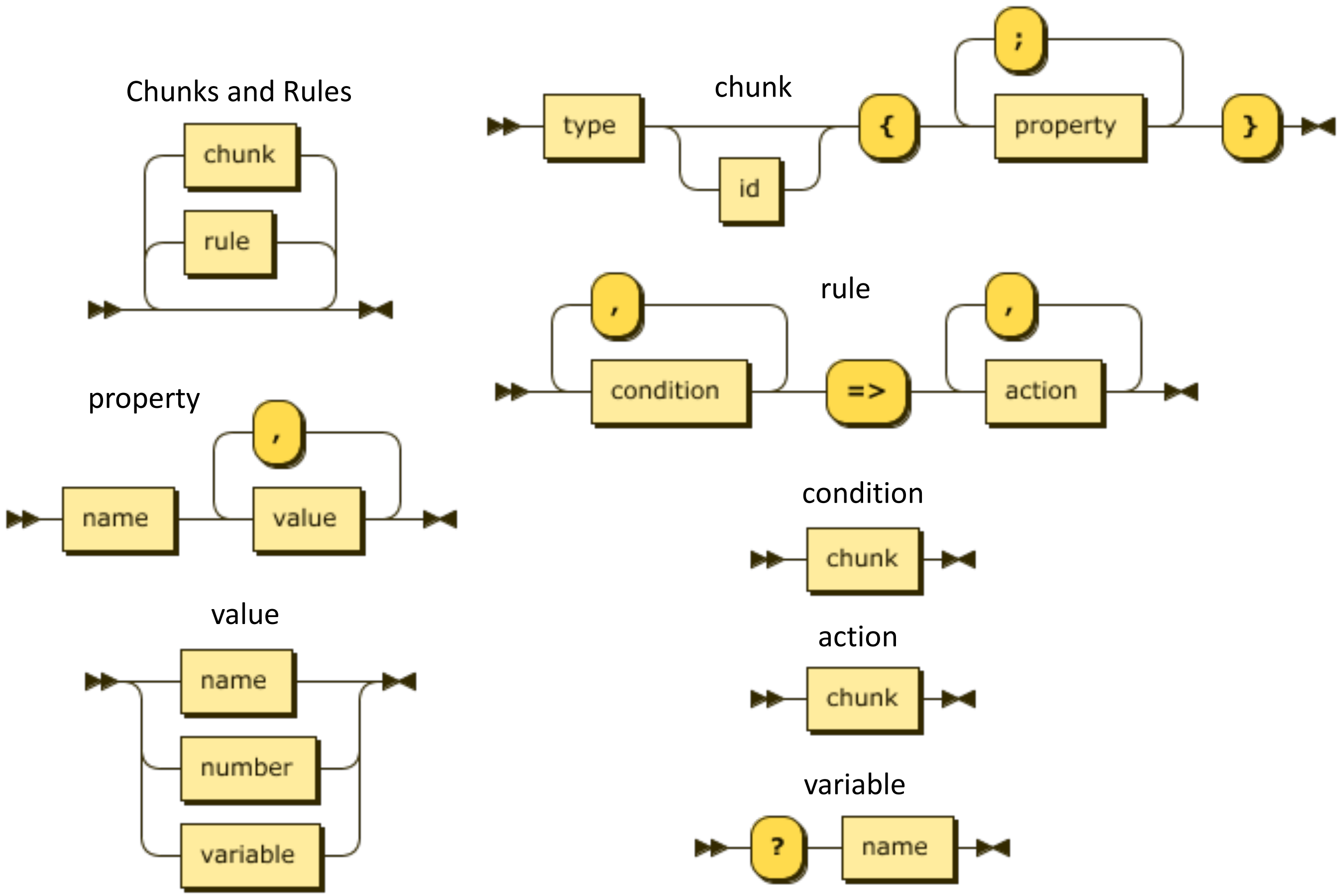
- Incoming shipments have low diversity of goods per truck
- Outgoing shipments have high diversity to suit customer needs
- Some goods must be shipped within tight time limits, e.g. fresh fruit and vegetables
- Balancing cost of inventory against resilience to disruptions
  - Just-in-time storage and delivery is sensitive to disruptions in supply

- Pallets are assigned to storage areas and outgoing shipments
- Idle forklifts are dynamically assigned to collect specific pallets
  - From incoming shipments to storage
  - From storage to outgoing shipments
- Robot forklifts need downtime to recharge their batteries

Chunks and Rules

higher level than RDF

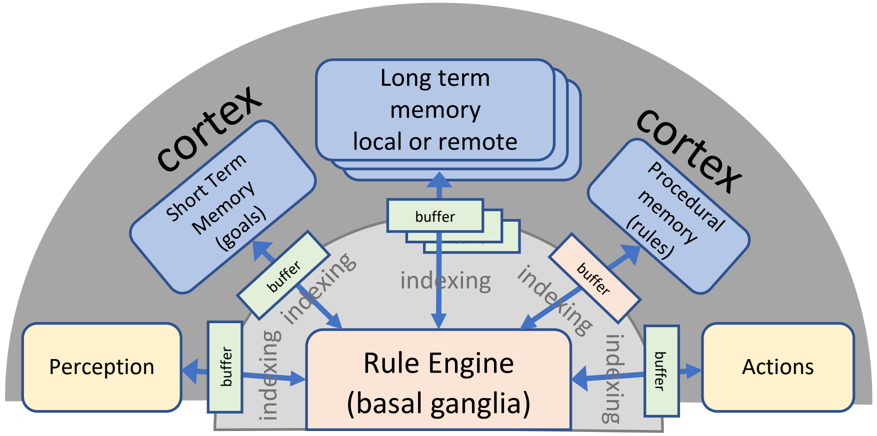
web-based demos for smart homes and factories



names beginning with “@” are reserved, e.g. @do for actions

See [W3C Cognitive AI Community Group]

Cognition – Sequential Rule Engine



Cognitive Buffers hold single chunks
Analogy with HTTP request-response model

- Inspired by John Anderson’s ACT-R and decades of cognitive science research at CMU and elsewhere
- Mimics characteristics of human cognition and memory, including spreading activation and the forgetting curve
- Rule conditions and actions specify which cognitive module buffer they apply to
- Variables are scoped to the rule they appear in
- Actions either directly update the buffer or invoke operations on the buffer’s cortical module, which asynchronously updates the buffer
- Predefined suite of cortical operations
- Reasoning decoupled from real-time control over external actions, e.g. a robot arm

Example Swarm Messages

- Messages signal events, invoke actions and signal their asynchronous results
- Cognitive rules work with chunks, which have an easier syntax than JSON
- Chunks map to RDF using context files similar to JSON-LD
- Swarm agent models describe which messages an agent supports akin to thing descriptions in the web of things
- Messages can be sent one-to-one or one-to-many

Here are some messages* that can be sent to the robot forklifts:

Using JSON:

```
{"action":"grab", "side":"front", "pallet":"pallet1"}
{"action": "release", "x":20, "y":30, "orientation":45}
{"action":"move", "x":20, "y":30, "gear":"forward"}
{"action":"move", "x":30, "y":20, "gear":"reverse"}
```

Using chunks:

pallets can be on the floor or on a rack or in a truck

```
grab {side front; pallet pallet1}
release {x 20; y 30; orientation 45}
move {x 20; y 30; gear forward}
move {x 30; y 20; gear reverse}
```

* The actual data formats will vary with the protocols used to communicate with IoT devices, and the above is from the perspective of the cognitive rules used to coordinate the swarm.

Swarm Management

Centralised Control

- Swarm coordinator allocates tasks, tracks where everything is, and computes routes for mobile agents
  - Centralised mapping service
- Messages exchanged between swarm participants and the coordinator (one to one)
- Single point of failure
- But simpler in respect to monitoring and control for business objectives

Decentralised Control

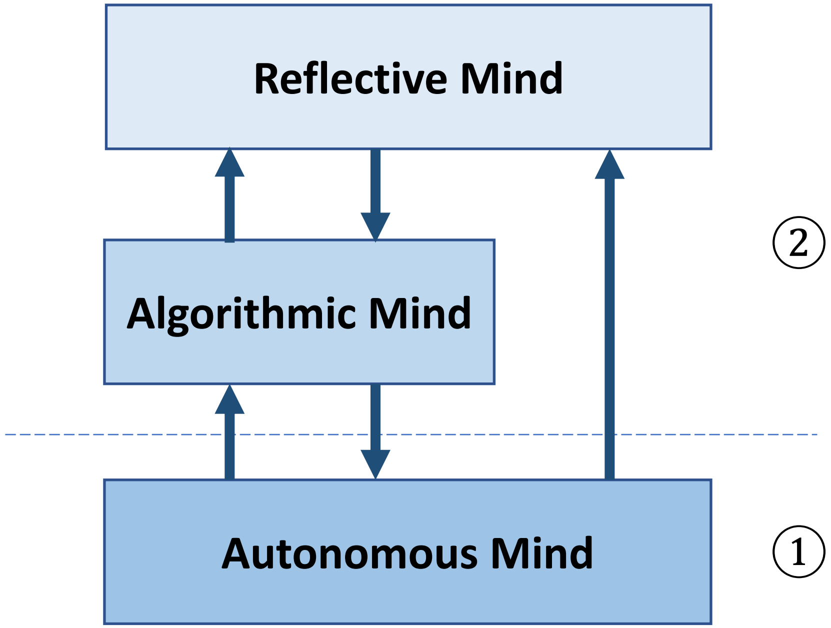
- Tasks allocated in a distributed way 1) request for service, 2) offers of service, 3) requester selects and notifies task provider
  - Offers can specify a future time, e.g. when a forklift expects to finish its current job
- Topic based message distribution (one to many) – service providers listen on topics relevant to what services they provide
  - Can be limited to nearby participants
- Geospatial streams together with agents that offer routing services

Perception as a distributed process of semantic fusion mimicking the human brain

Cognitive Agents

- Class of agents that make informed decisions on what actions to take
- Perception is a distributed process of building higher level models of each agent's environment
- Cognition is process of reasoning to decide on what actions to take – using a mix of type 1 and type 2 processing
  - **symbolic systems** using handcrafted knowledge graphs and rules
  - **non-symbolic systems** using artificial neural networks trained on very large datasets, plus transfer learning on smaller datasets and reinforcement learning with human feedback

Keith Stanovich's Tripartite Model of Mind



Type 1 processing is fast, automatic, and opaque, e.g. recognising a cat in a photograph or a traffic sign when driving a car.
Type 2 processing is slow, deliberative, and open to introspection, e.g. mental arithmetic. It is formed by chaining Type 1 processes using working memory.

See, e.g. "Dual-Process Theories of Higher Cognition: Advancing the Debate", Evans and Stanovich (2013), along with "Thinking Fast and Slow", Daniel Kahneman (2011)

Questions?

n.b. I hope to work on smart factories as a further use case, and there are many other potential use cases, e.g. urban traffic management, and logistics at container ports.

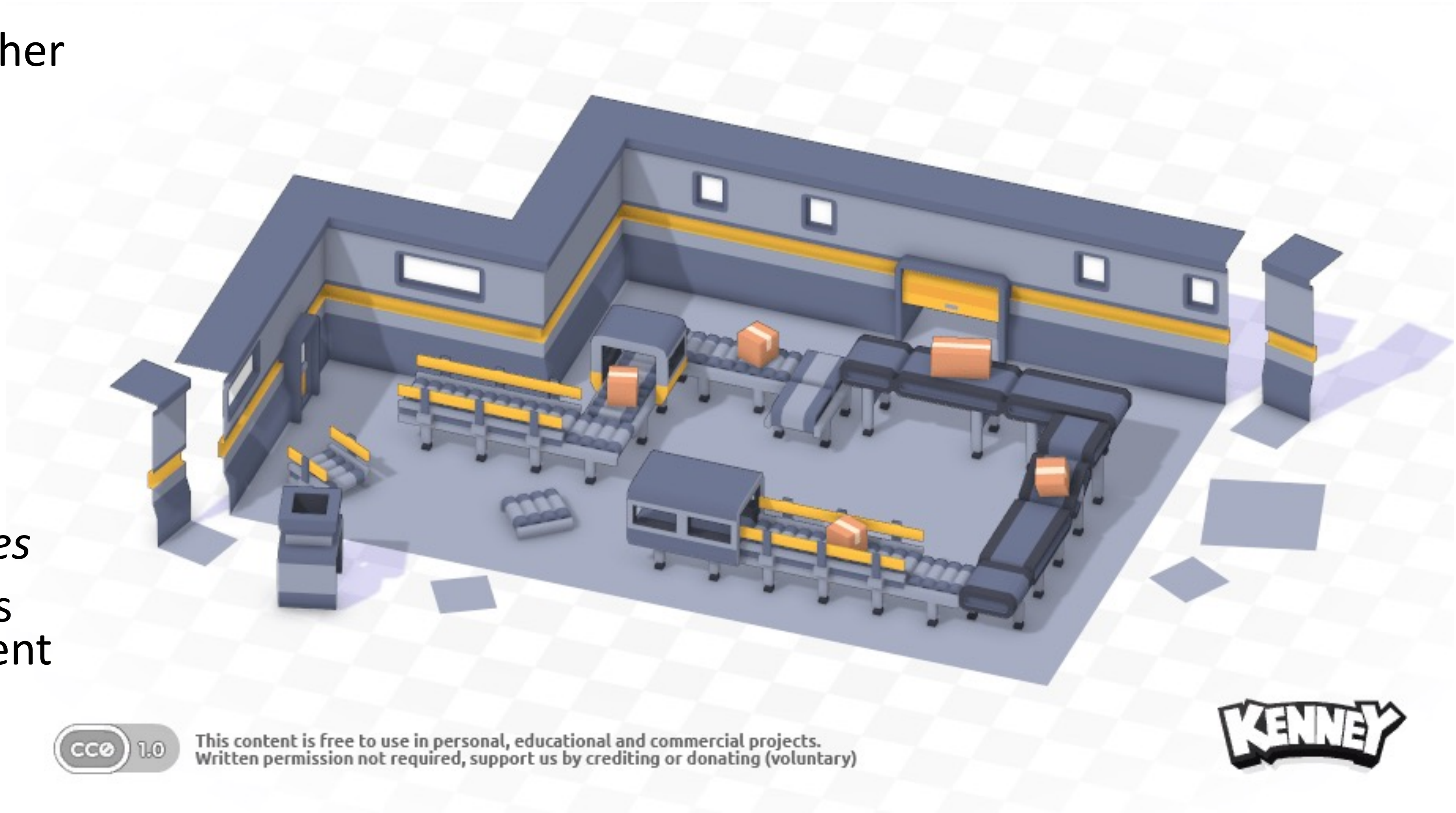
Indexing and Neighbours

- Use spatial indexing to limit rendering to the visible part of a very large scene
- Spatial indexing also helps to determine other nearby mobile agents as part of collision avoidance
- Quad-tree indexing using recursive subdivision into rectangles or triangles
- Potential for collisions*
  - Each mobile agent knows its location, speed and direction
  - Shared with nearby agents to detect potential collisions
- To avoid collision, agents either turn away or give way until the path is clear
- Local course recovery after collision avoidance

* Inspired by FLARM systems for gliders and light aircraft, that transmit position and speed vectors for use by intelligent motion prediction algorithms, and warn the pilots as needed.

Factory Simulation

- Smart factories are another potential application
- Robot arms
- Milling machines
- Painting
- Conveyor belts
- Movable racks
- AMRs
- *and many other machines*
- People – as real factories use people to complement automation



See: https://kenney.nl/assets/conveyor-kit

Urban Traffic Management

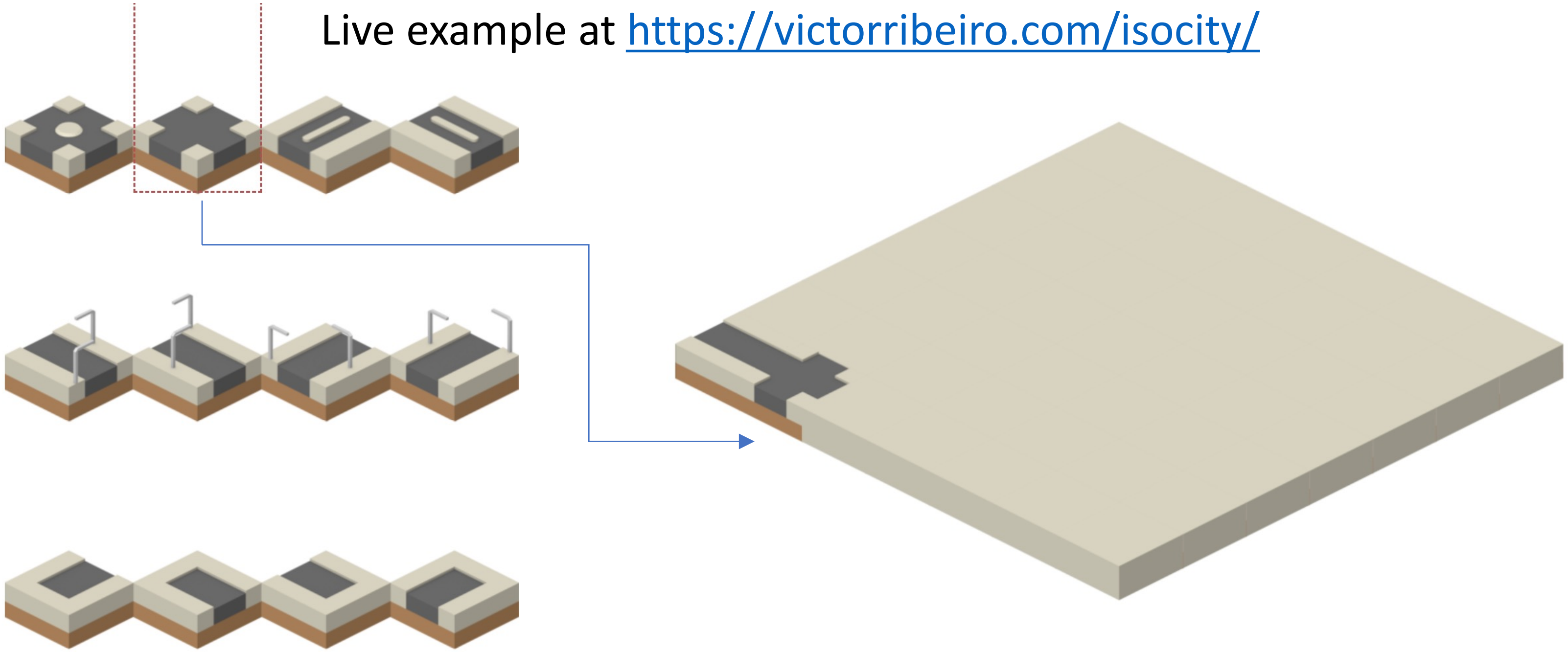
- Isometric projection enabling city scale simulations
- Composed from collections of image tiles
- Generated from good enough 3D models
- Iconic rather than photo realistic

See: https://github.com/victorqribeiro/isocity

Urban Traffic Management

- We could even enable users to build their own cities in a web browser
- Or select from pre-existing models
- Pan, zoom and rotate* the field of view

Live example at https://victorribeiro.com/isocity/



* Through fixed set of angles, e.g. 45° intervals using tile sets, such as below

Urban Traffic Management

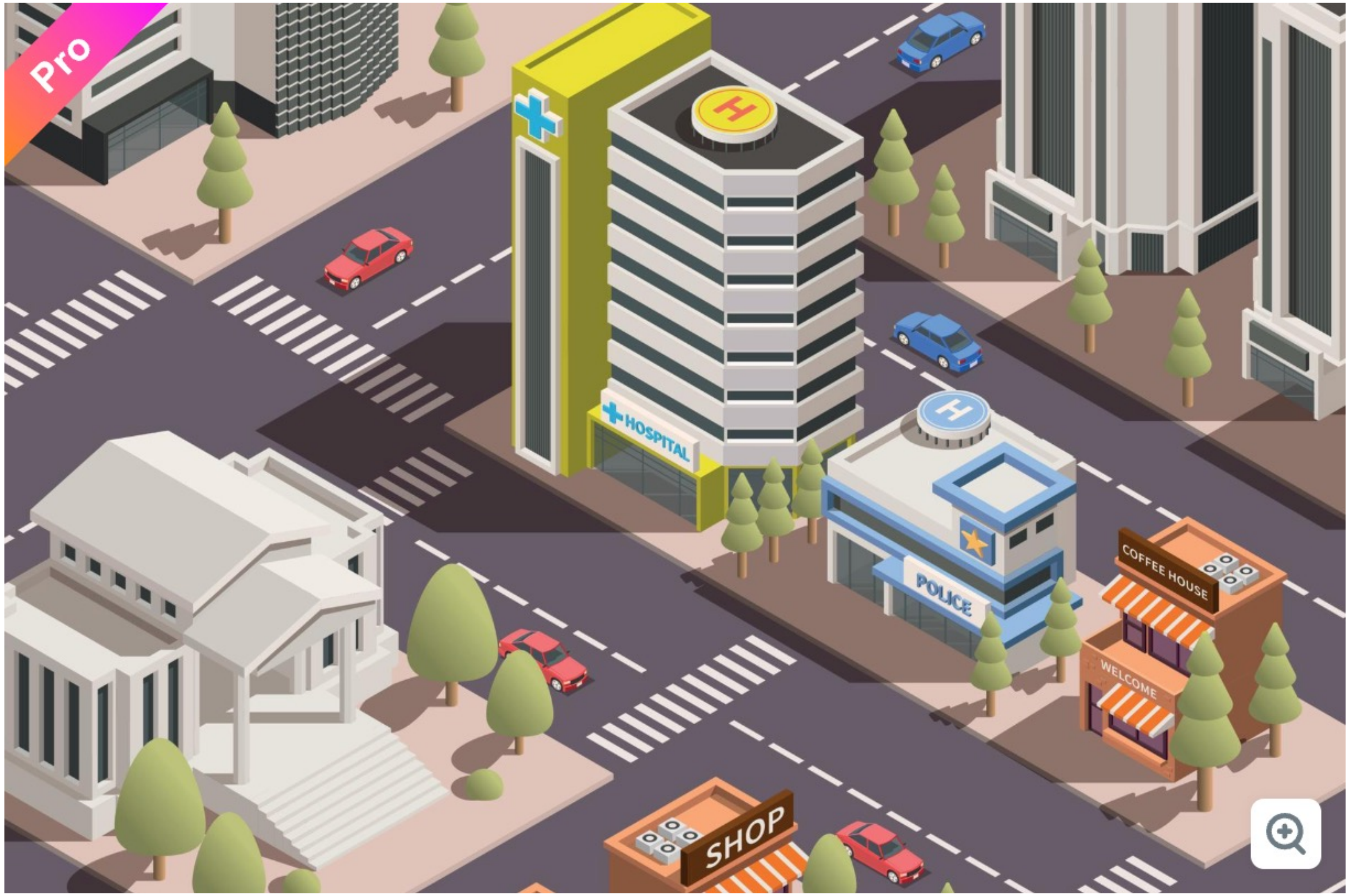
- Here is a larger static example from *shutterstock* illustrating the potential
- Many different components that can be configured as needed
- Each component is associated with its behaviour

See: https://www.shutterstock.com/image-vector/isometric-urban-megalopolis-top-view-city-582946510

Urban Traffic Management

- Close up of just one type of road junction
- Challenges for large scale simulations*
- Could include cars, trucks, cyclists, and pedestrians, e.g. mothers with prams, old people with walking sticks, and young children

* Lower fidelity simulation outside field of view



See: https://www.vecteezy.com/vector-art/4564141-modern-city-isometric-illustration

Container Port Logistics

- International trade depends on efficient handing of containers
  - Transported on ships, trucks and trains
  - Minimising delays
  - Maximising throughput
- Warehouses for redistribution when containers carry loads for multiple customers
- Requirements for customs inspections and tariffs

See: https://www.shutterstock.com/image-vector/beautiful-isometric-vector-set-port-terminal-1863706453