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A MULTI-METHODOLOGY AGENT-BASED APPROACH FOR CONTAINER LOADING

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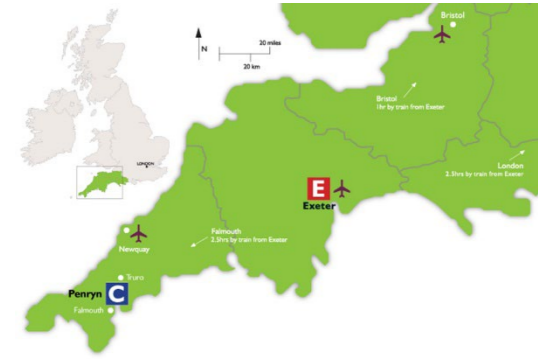
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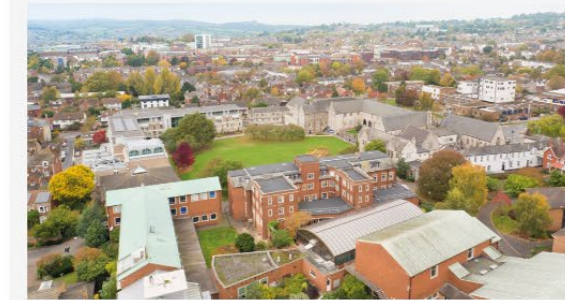


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- Three campuses in the South West England
- 25,000 students from 130 countries
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Streatham Campus, Exeter



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Mission: To identify, develop and apply advanced simulation, analytics and modelling methods to business problems.

<p>Themes</p> <ul style="list-style-type: none"> Smart Cities Healthcare Service Innovation 	<p>Research Grants</p> <p>Industrial Strategy AoTF, Horizon2020, INTERREG, NERC, EPSRC, ESRC, The Leverhulme Trust, Health Charities (TMRF), Academic Health Sciences Network</p>	<p>Projects/Fellowships</p>
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Outline of Presentation

- Motivation
- CLA and Agent Based Simulation
 - Existing work
- Proximity-based modelling using agents
 - Methodology
 - Agent-based Model (Layout of Agents; Inter-Agent Relationship)
 - Experiments
 - Results
- Conclusion
- Future work

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Computer Simulation in OR/MS

Simulation is the process of creating computer models of a real or proposed system and performing experiments with these models.

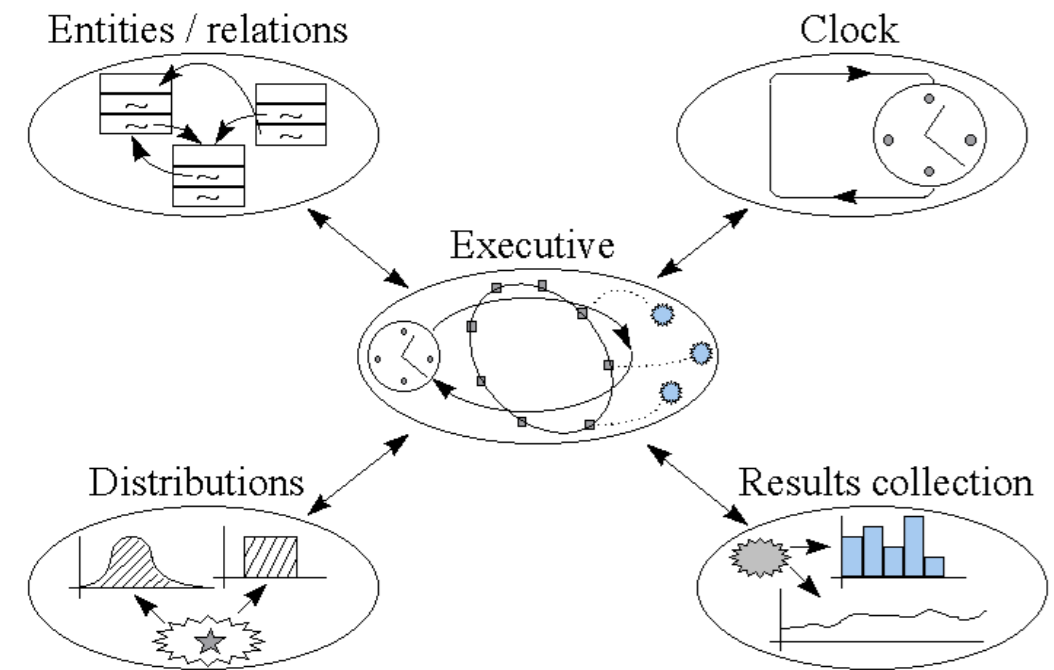
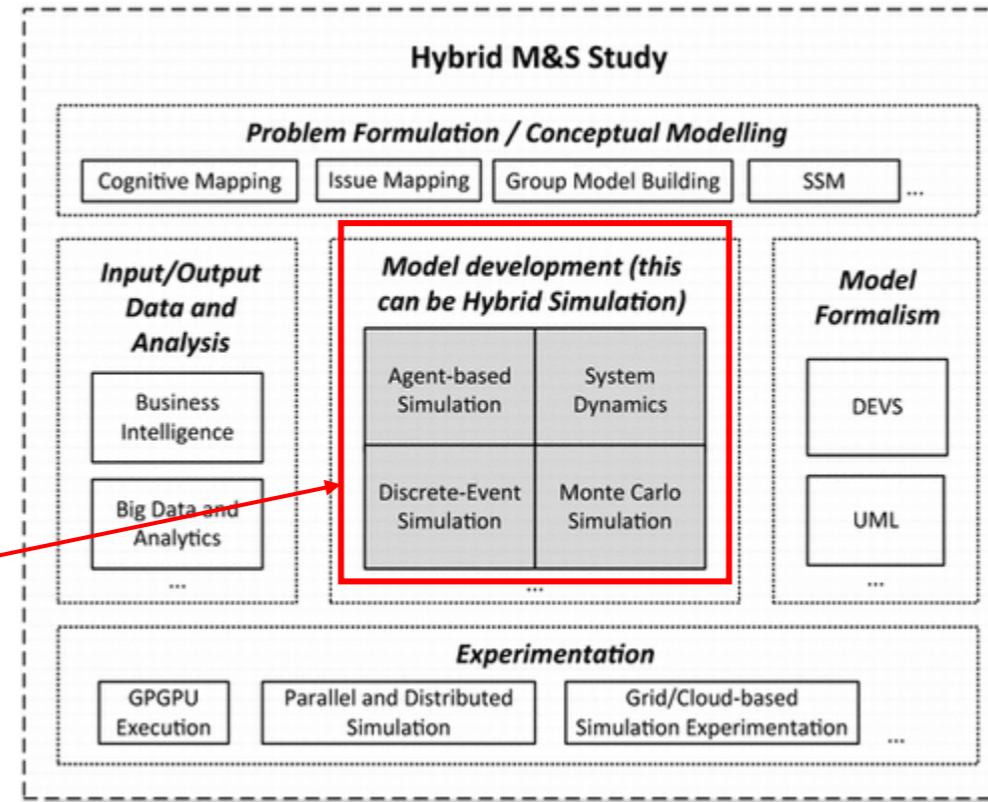
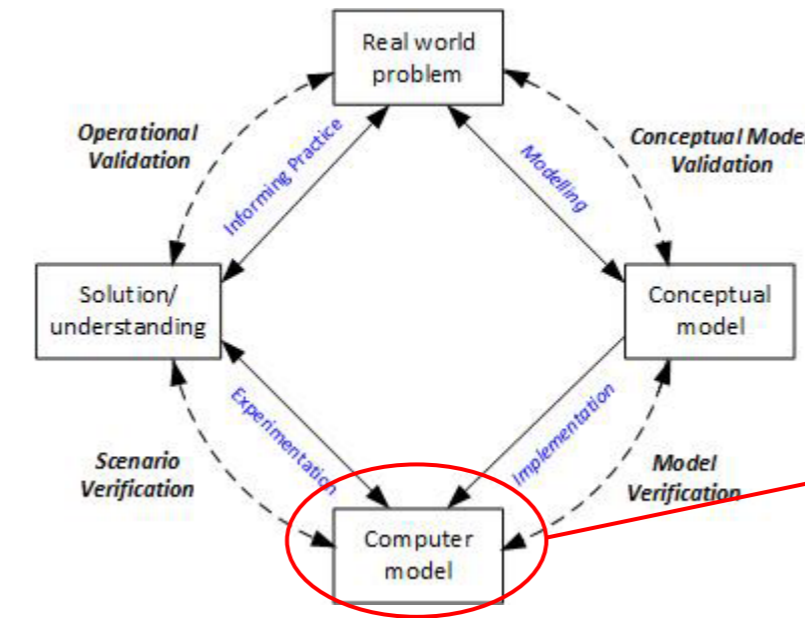


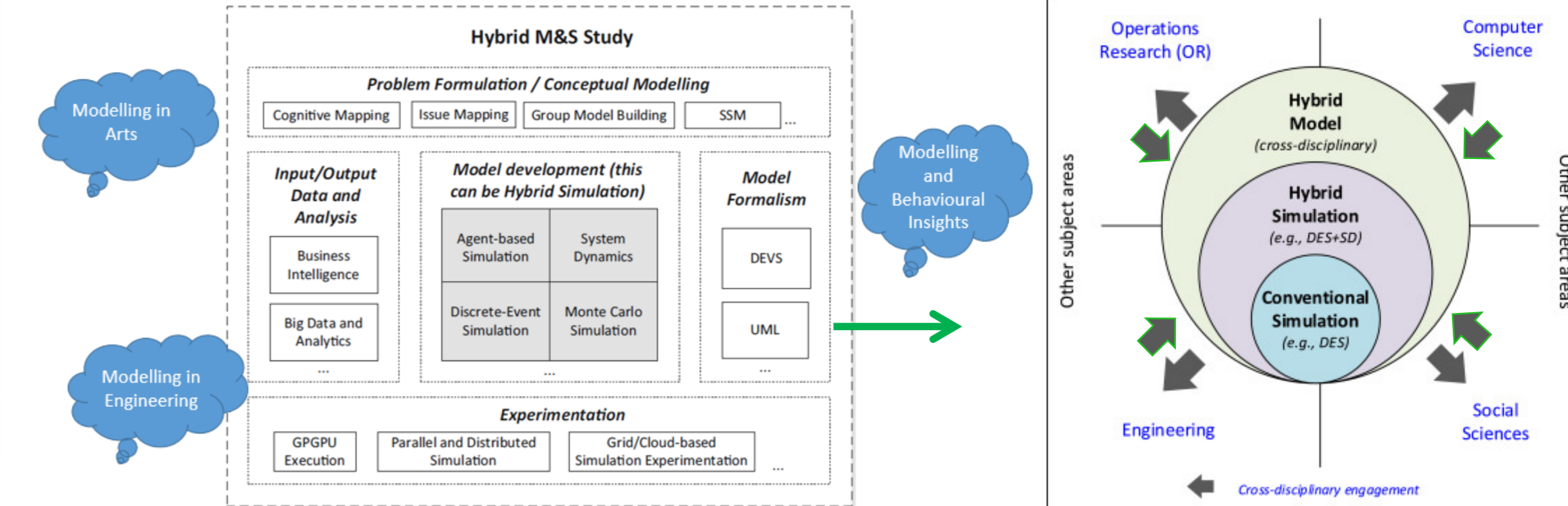
Figure 2. Structure of a simulation system (adapted from Kreutzer, 1986)

- Advantages
 - “What if?” analysis
 - Faster than real systems
 - Repeatability
 - Inexpensive monetarily
 - Experiment before you implement!

From Simulation to Hybrid Simulation



From Hybrid Simulation to Hybrid Modelling



[http://masters.donntu.edu.ua/2006/kita/kondrakhin/library/art6.htm#Using simulation](http://masters.donntu.edu.ua/2006/kita/kondrakhin/library/art6.htm#Using%20simulation)

Robinson, S. (2004). *Simulation: The Practice of Model Development and Use*. Wiley.

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Motivation

- Hybrid Modelling and Simulation
 - Soft OR techniques like Soft Systems Methodology with quantitative OR technique.
 - Markov Modeling and Monte-Carlo Simulation
 - Agent-Based Simulation and Optimization Algorithms (like “Packing and Cutting”)
 - Discrete-Event Simulation and Optimization
 - Hybrid Simulation - e.g., System Dynamics and Discrete-Event Simulation
 - DES and Machine Learning

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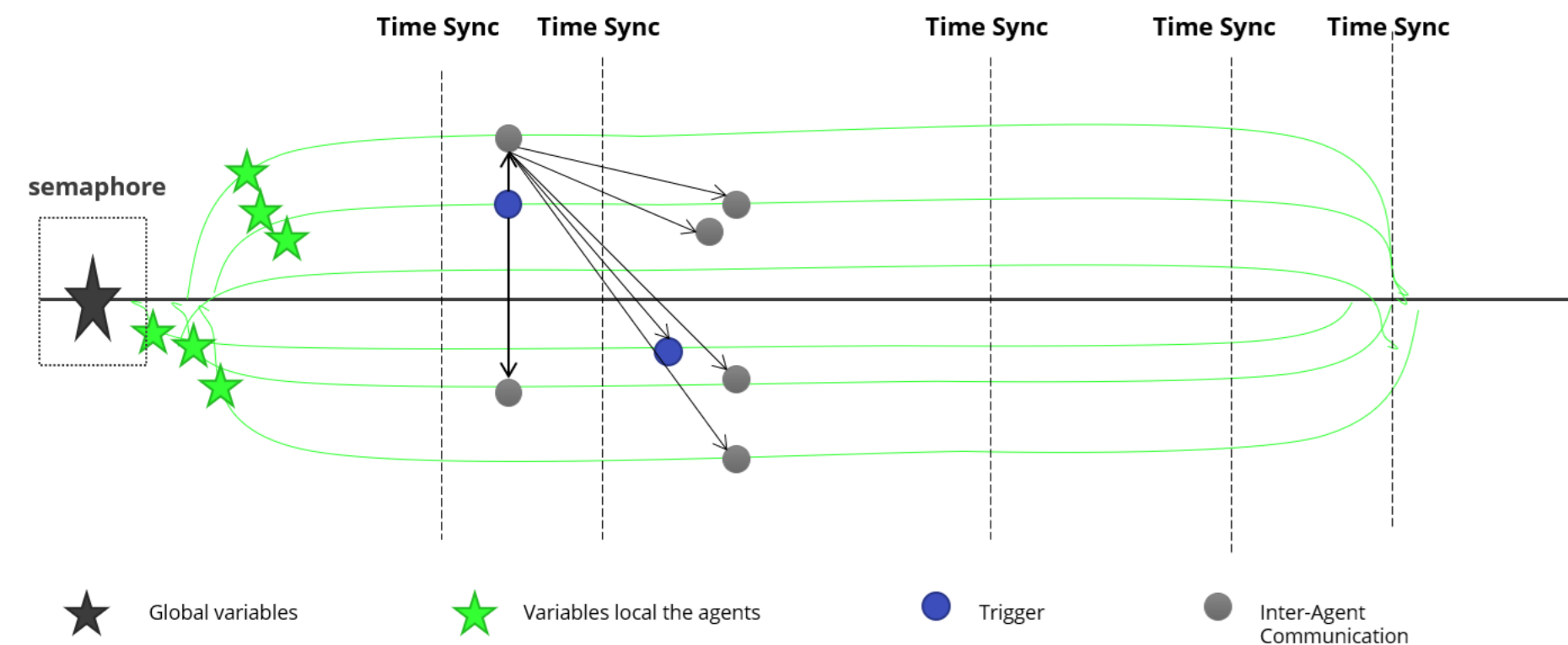
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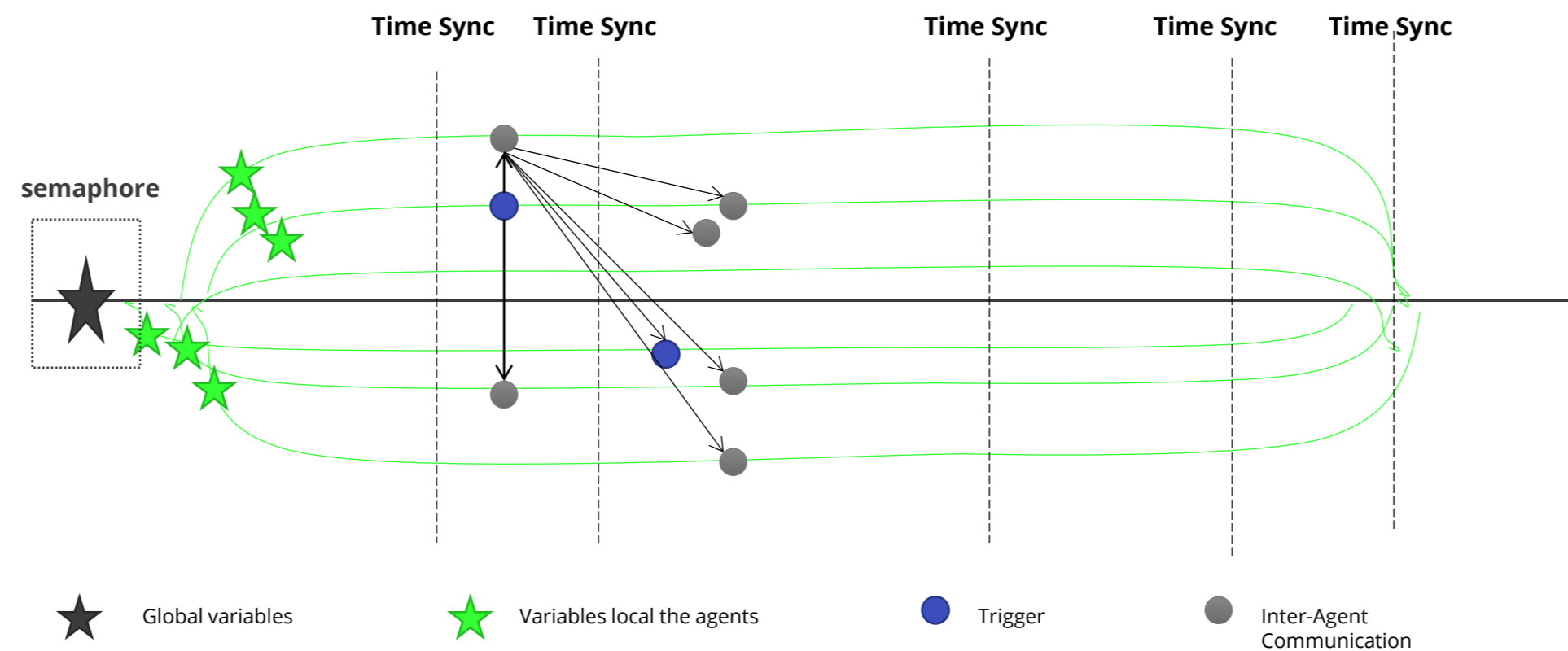
Agents, Threads, Time Synchronisation, Inter-agent Communication

Focus on individual objects (agents), its properties and behaviour, its communication with other agents.



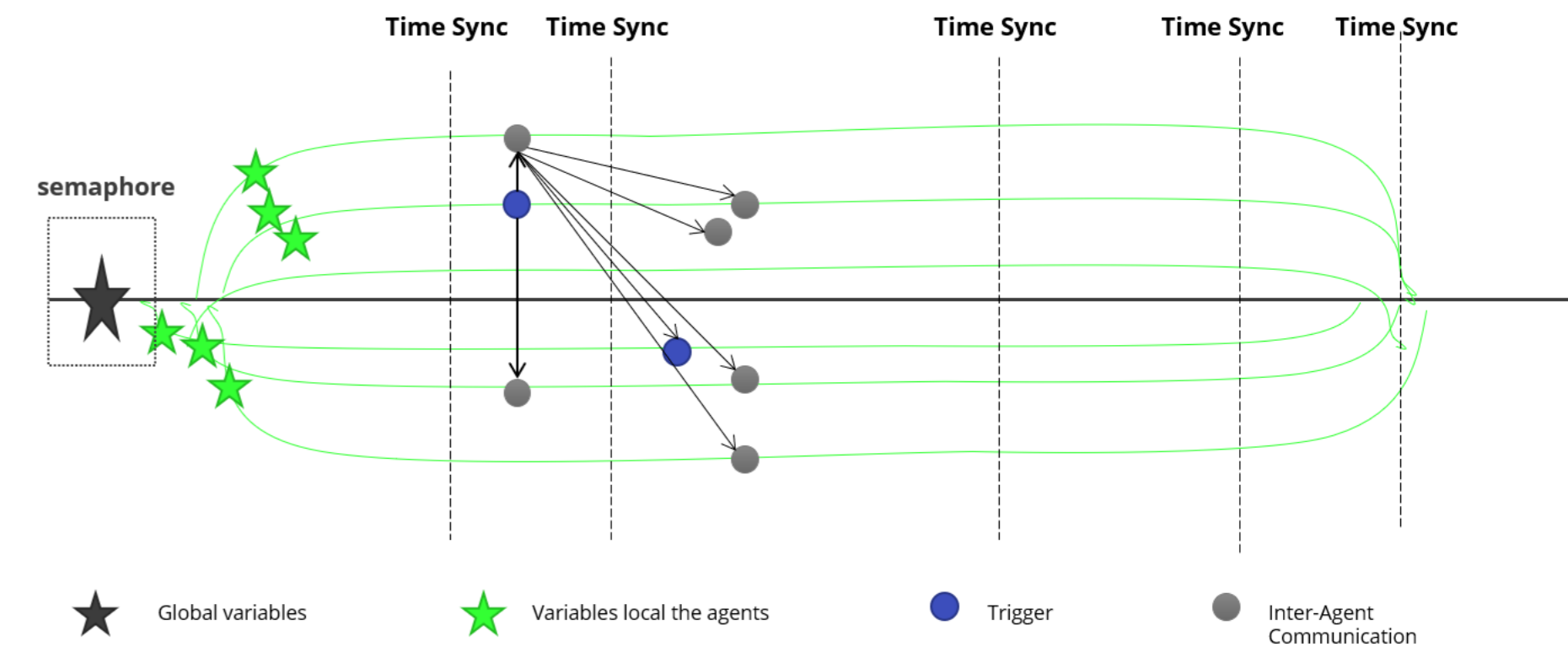
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Existing Research in Container Loading Algorithm

- The efficient loading of cargo into freight containers - and, more generally, the proficient packing of smaller items into larger objects - has been a subject of intensive research for at least thirty years.
 - **Single-pass heuristics, genetic algorithms, tabu search, linear programming, random search, combinations of tree-search heuristics and dynamic programming**
 - Review of literature: Parreño et al. (2008); Wang, Li and Levy (2008); Huang and He (2009); Fanslau and Bortfeldt (2010); Egeblad et al. (2010); Pisinger (2002); Wäscher, Haußner, and Schumann (2007).

Existing Research in Container Loading Algorithm

- More recent work has moved away from pure bin-packing formulations of the container loading problem and has paid increasing attention to various additional factors.

Existing Research in Container Loading Algorithm

- **Orientation constraints on individual types of cargo** (Fanslau and Bortfeldt 2010)
- **Container weight capacity limits** (Gehring and Bortfeldt 2002)
- **Weight distribution within a container** (Gehring and Bortfeldt 1997, Davies and Bischoff 1999, Eley 2002)
- **Cargo stability** (Bortfeldt and Gehring 1998, 2001; Terno et al. 2000; Mack et al. 2004; Moura and Oliveira 2005).
- **Load bearing ability of items** (Ratcliff and Bischoff 1998, Bischoff 2006).

Existing Research in ABS – specific to problem domain

- ABS has also been applied to container management, as opposed to container loading.
 - Henesey (2006) investigated the **use of agent-based technologies to improve the performance of container terminals**.
 - **The use of an ABS architecture to solve the automatic container allocation problem** in a port container terminal is described by Rebollo et al. (2000).
 - **The use of agents to simulate and optimize cargo handling storage space** in a maritime port is reported by Kefi et al. (2009).

Existing Research in ABS – specific to problem domain

- ABS has been used to **model the management of stakeholder relations** in container terminals through use of agents that simulate different stakeholder behavior (Henesey, Notteboom, and Davidsson 2003).
- Henesey, Davidsson and Persson (2006) report on **the use of the SimPort ABS tool to evaluate eight transshipment policies**.

Existing Research in ABS – specific to problem domain

- Bin, Wen-Feng, and Yu (2009) have used ABS, utilizing 14 kinds of agents, to **model a container terminal logistics system**.
- The project Container World has **modeled both business and operational aspects of the container business in the UK through a multi-agent methodology** (Sinha-Ray et al. 2003).

Why CLA and ABS?

- The purpose of the combined CLA and ABS approach to container loading is **to find the trade-off between container loading efficiency** and various important practical considerations in relation to the cargo - such as, its **stability**, fragility, volatility of cargo, and **cross-contamination**.

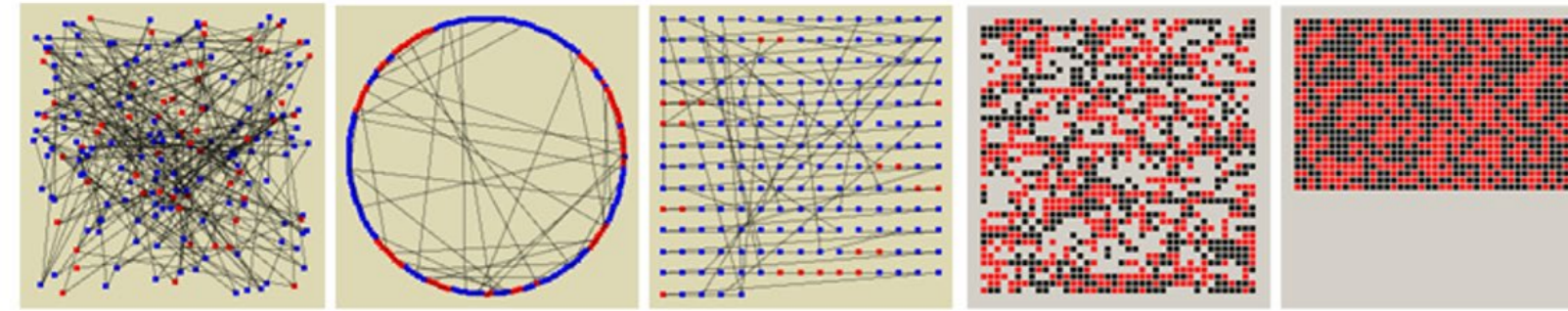
Why CLA and ABS?

- In this paper, only the ***knapsack version of the problem*** is considered, wherein the space available is fixed and loading all the cargo may not be possible. ***The cargo may consist of items of various degrees of heterogeneity.***

Why CLA and ABS?

Agent Characteristics	Cargo Stability Scenario	Cargo Cross-Contamination Scenario
(1) Agents have properties	Dimension of the individual items of cargo (length, breadth, height).	Freshness index (i.e., the length of time after which the individual items will start developing mold).
(2) Agents exhibit autonomous behavior	The stability of an item is usually dependent on the dimensions of the item and other factors (e.g., weight).	The freshness index will usually decrease over time.
(3) Interaction between agents may result in more complex behavior	The stability of an individual item may also depend on the stability of the items that surround/support the item in question.	Perishable items may develop mold when they come in contact with other mold-affected items.

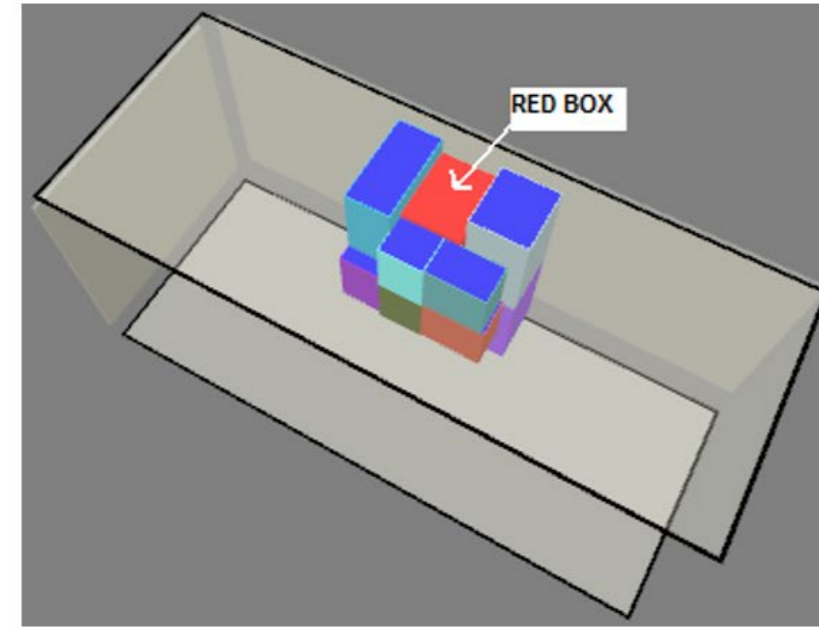
Layout of Agents and Inter-Agent Relationship



Random Layout Ring Layout Arranged Layout Random Layout (discrete space) Arranged Layout (discrete space)

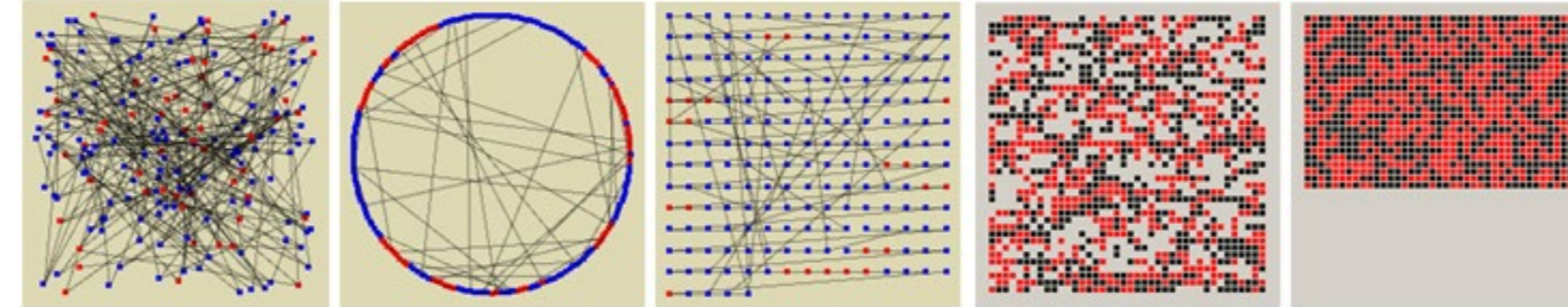
Agent Networks:

- Random Network
- Distance-based Network
- Ring Lattice
- Small World
- Scale Free (hubs and hermits)
- **Modelling of contact dynamics**



Mustafee, N., & Bischoff, E. E. (2013). Analysing trade-offs in container loading: combining load plan construction heuristics with agent-based simulation. *International Transactions in Operational Research*, 20(4), 471-491.

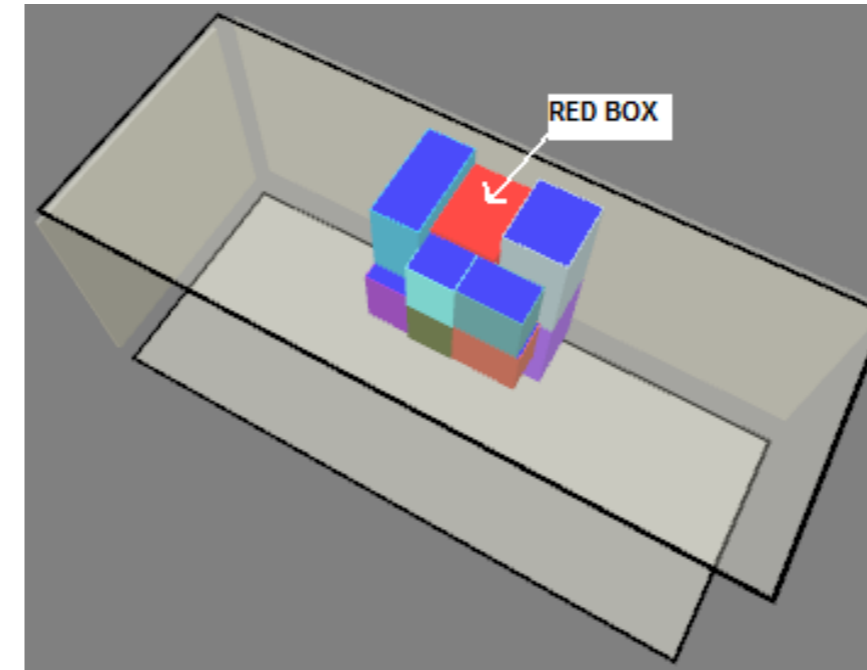
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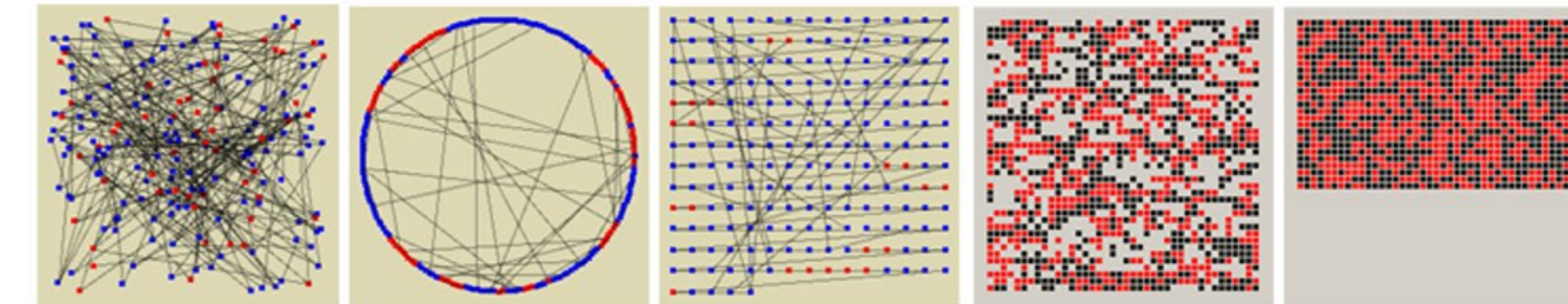
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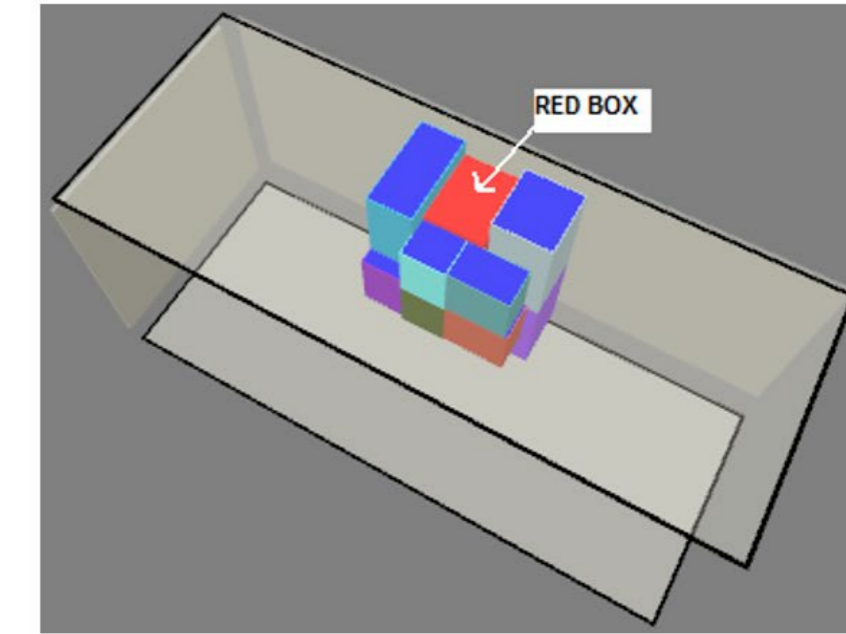
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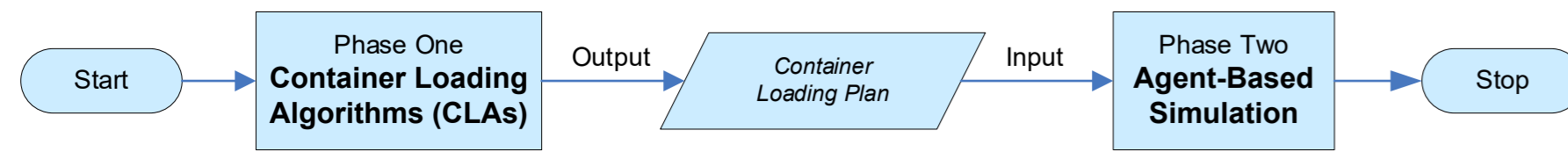
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CLA and ABS (first iteration)

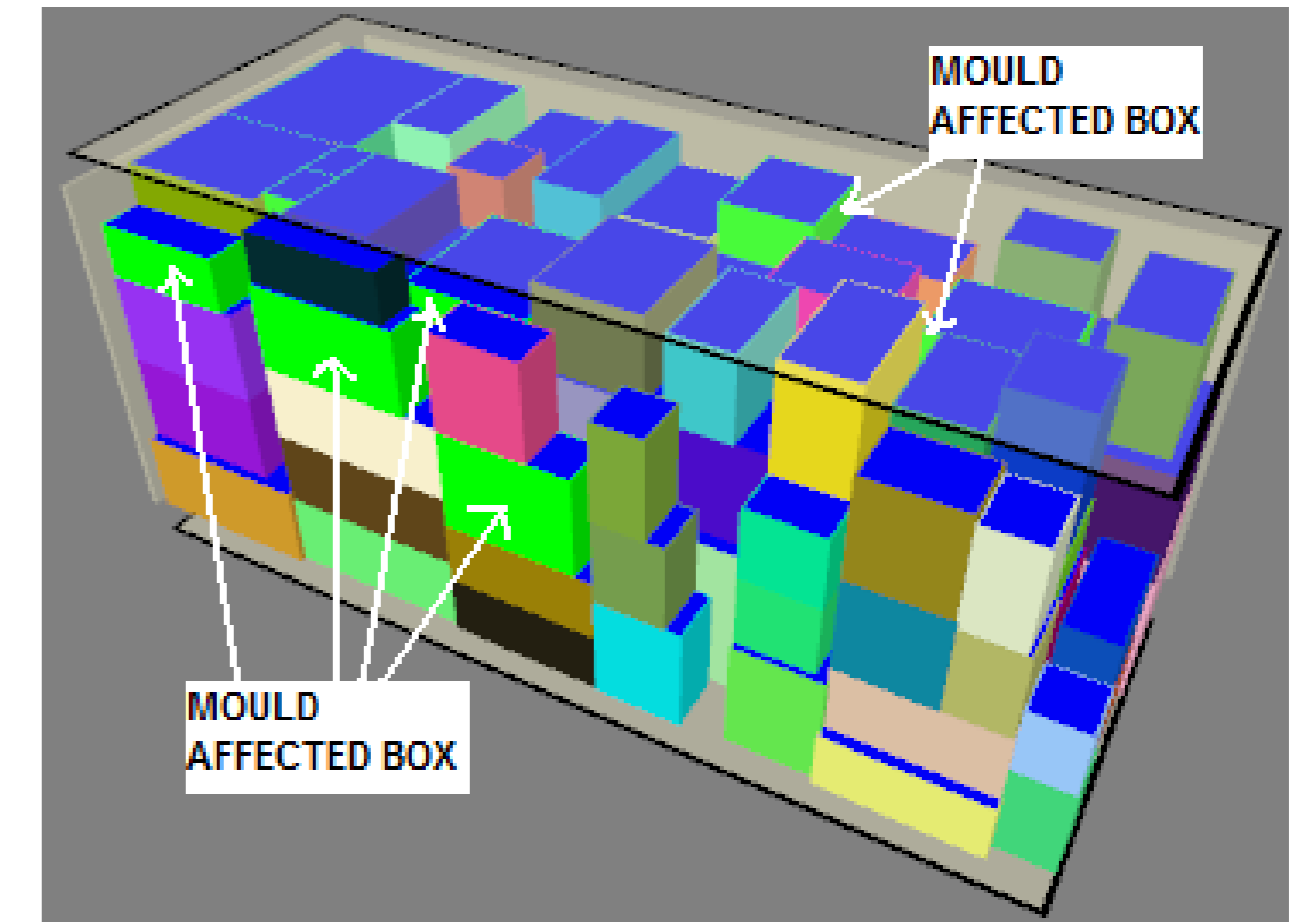


CLA → outputs load plan

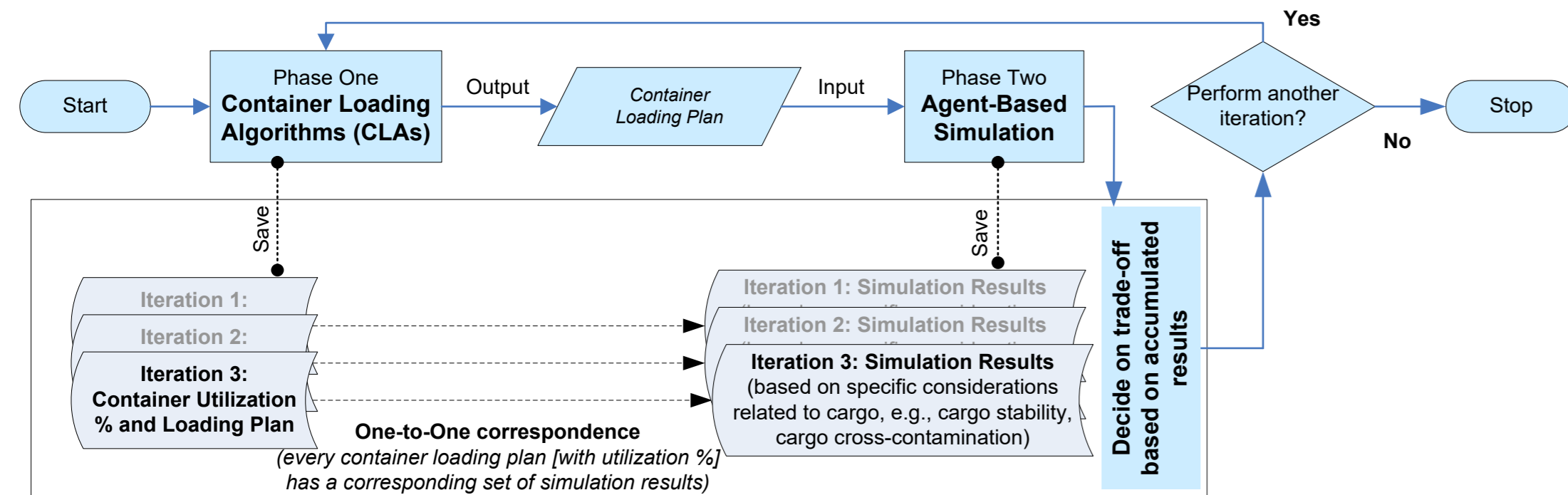
1	587	233	220	Physical space dimensions			Number of items
2	66						
3	0	0	0	99	120	73	57
4	0	120	0	120	193	99	57
5	99	0	0	198	120	73	57
6	120	120	0	240	193	99	57
7	198	0	0	271	120	99	57
8	240	120	0	339	193	120	57
9	271	0	0	375	74	65	24
10	339	74	0	413	178	65	24
11	375	0	0	440	74	104	24
12	413	74	0	478	178	74	24
13	339	178	0	420	233	92	18
14	420	178	0	501	233	92	18
15	478	0	0	559	92	55	18
16	478	92	0	559	147	92	18
17	501	147	0	556	228	92	18

X, Y and Z co-ordinates Length, Breadth and Height Freshness Index

ABS → Models contact dynamics



CLA and ABS (multiple iterations)



CLA → outputs multiple load plans

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X, Y and Z co-ordinates Length, Breadth and Height

Freshness Index

ABS → Models contact dynamics for every iteration

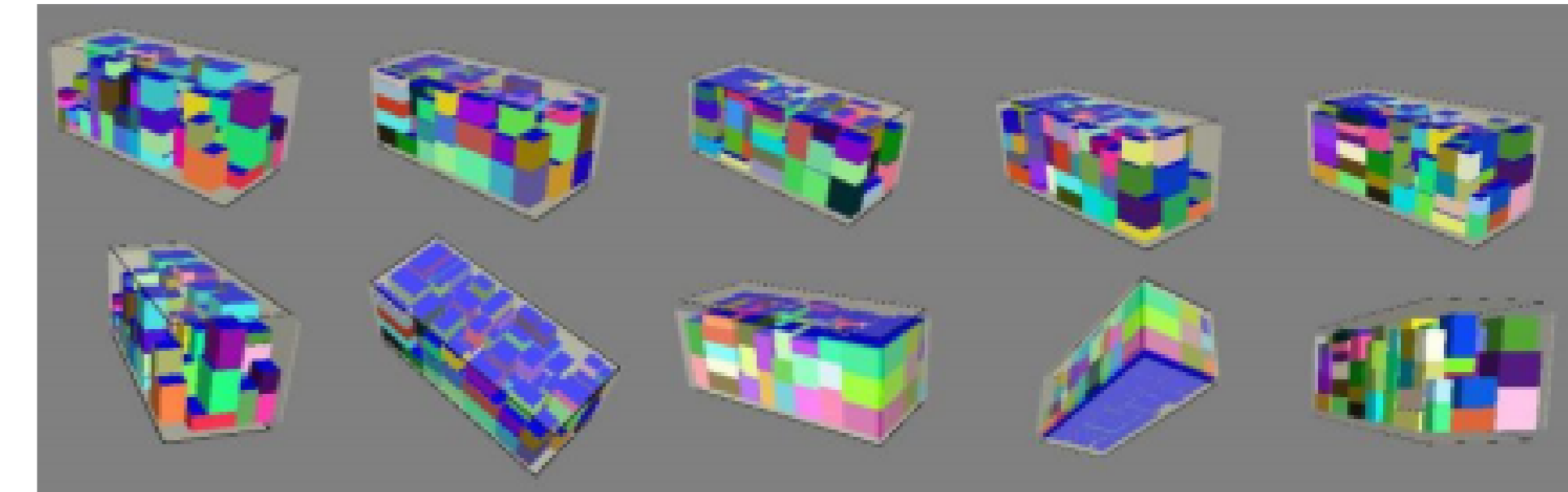


Figure 3: CPO algorithm being used to generate various layouts for the location-aware agents and to create inter-agent relationships between them. The agents are represented by the individual boxes in the confined space. The data is visualised using AnyLogic.

Overview of Proximity-based modelling using agents

- Cross-contamination of cargo items during storage and/or transportation, wherein several boxes of degradable items are stored in close proximity
- Proximity modelling of cross-contamination

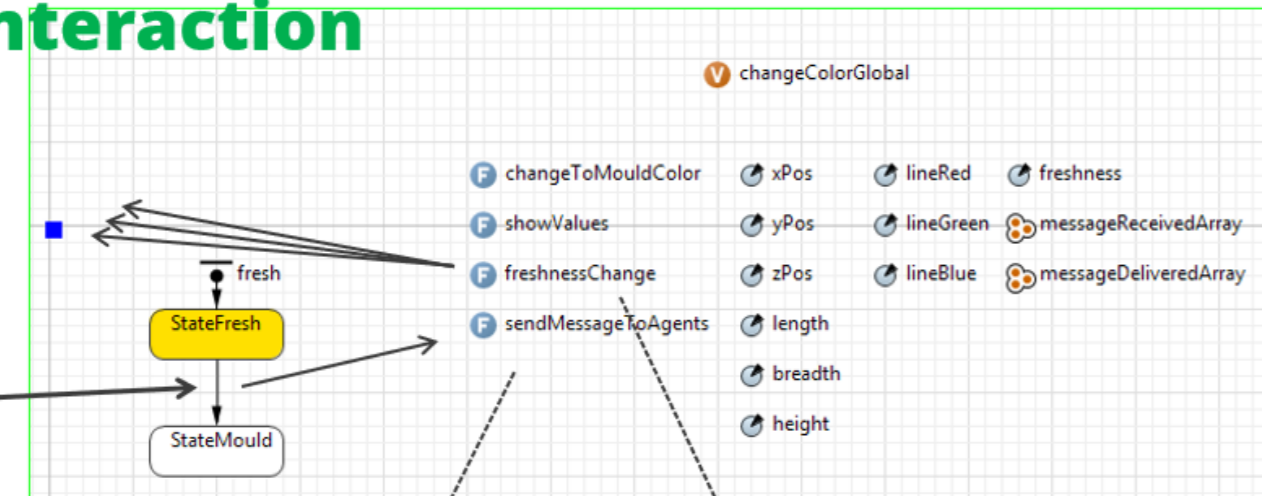
Overview of Proximity-based modelling using agents

- Two OR techniques - Cutting and Packing Optimisation (**Container Loading Algorithms**) and Simulation (**Agent Based Simulation**)

Overview of Proximity-based modelling using agents

- Feasibility study
- Objective is to investigate the trade-off between optimisation of physical space for storage/transportation and the potential for cross-contamination among boxes containing perishable clinical items

Inter-agent Interaction



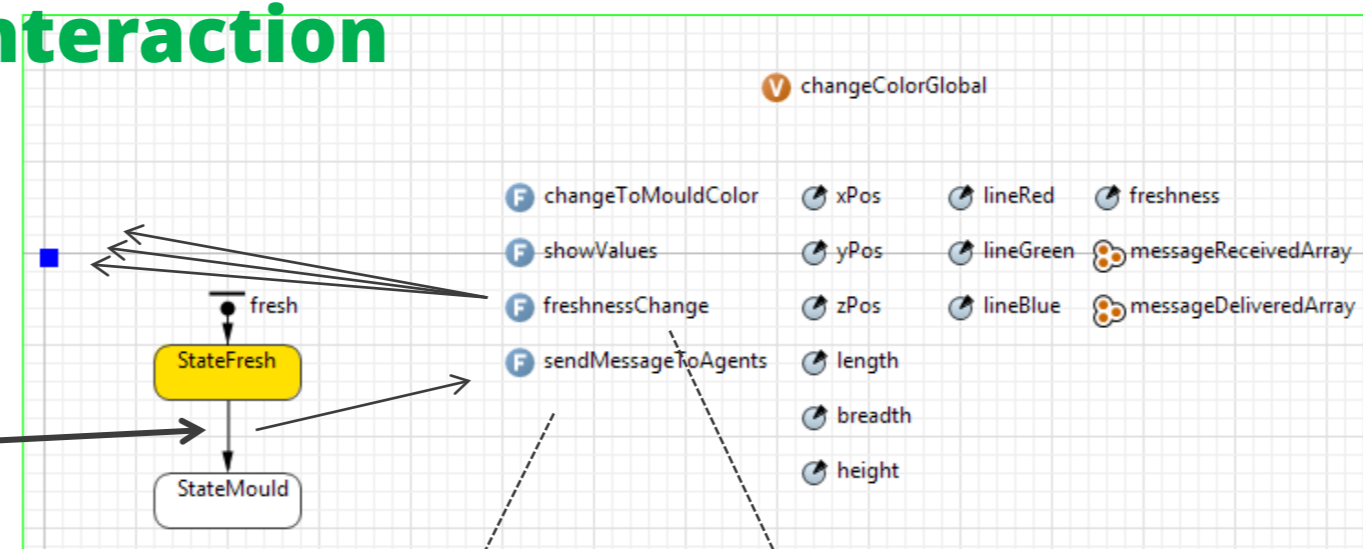
TRANSITION

```

Current Logical Time :6.0
Freshness Threshold Reached :5.0      Agent :50
Sending Message to : 40
Sending Message to : 41
Not Sending Message to : 51
Sending Message to : 58
Sending Message to : 59
Sending Message to : 61
Sending Message to : 62

[** FIRST MESSAGE**] Received by : 62   Received from [IN LIST] : 50   New value of Freshness : 33.0
[** FIRST MESSAGE**] Received by : 61   Received from [IN LIST] : 50   New value of Freshness : 11.0
[** FIRST MESSAGE**] Received by : 59   Received from [IN LIST] : 50   New value of Freshness : 18.0
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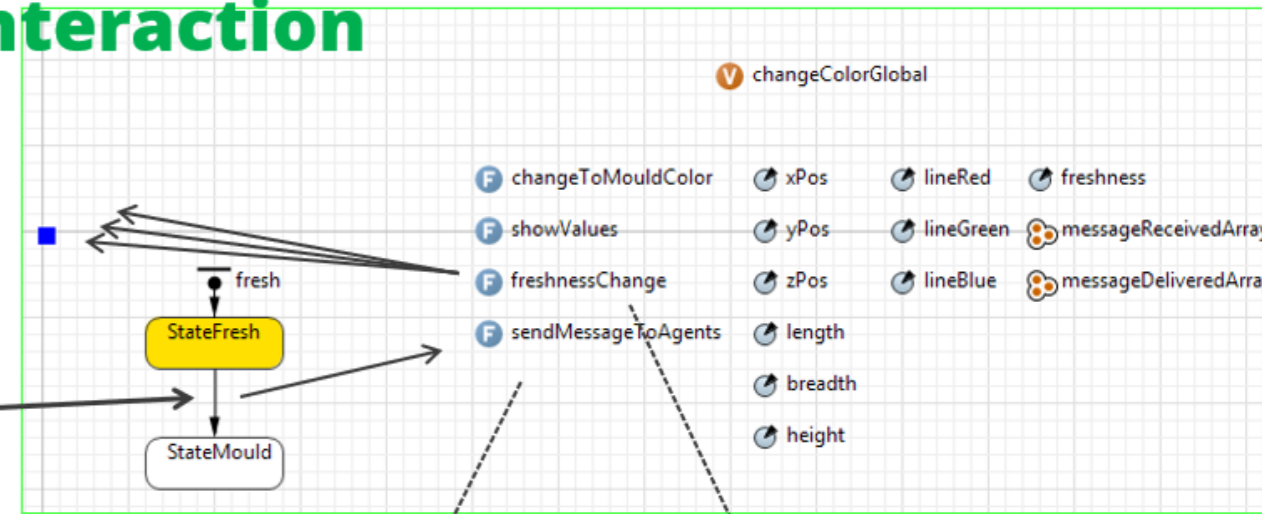
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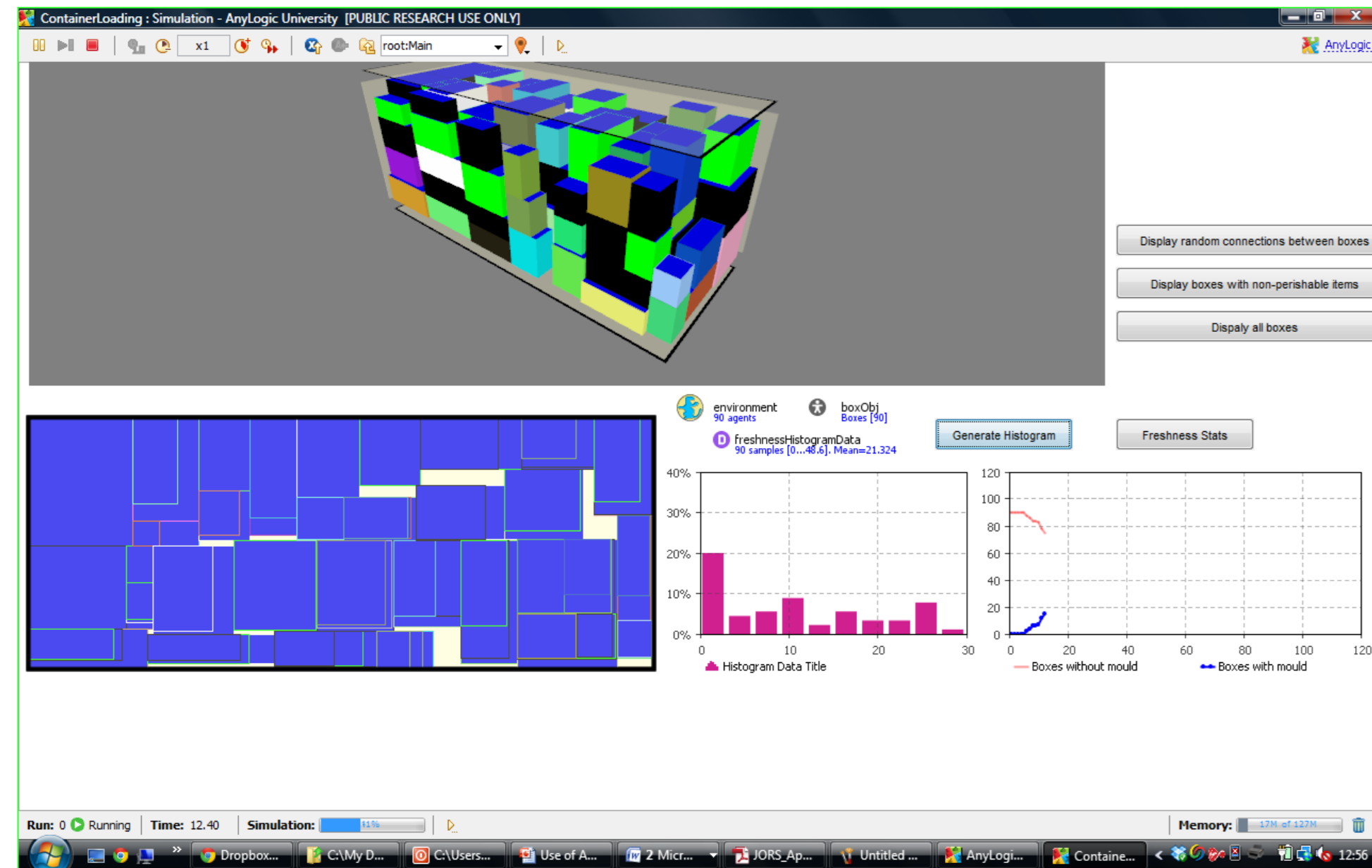
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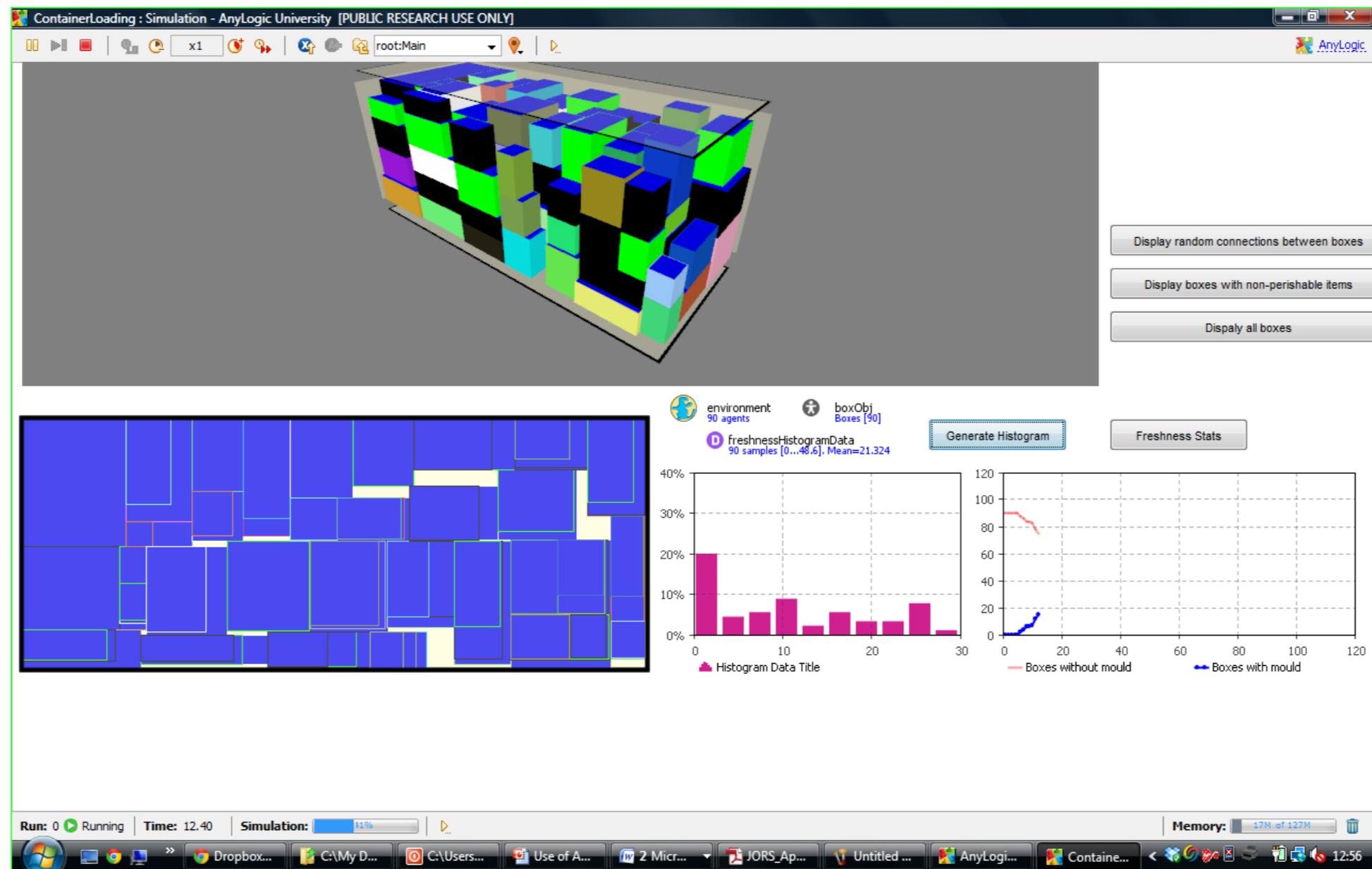
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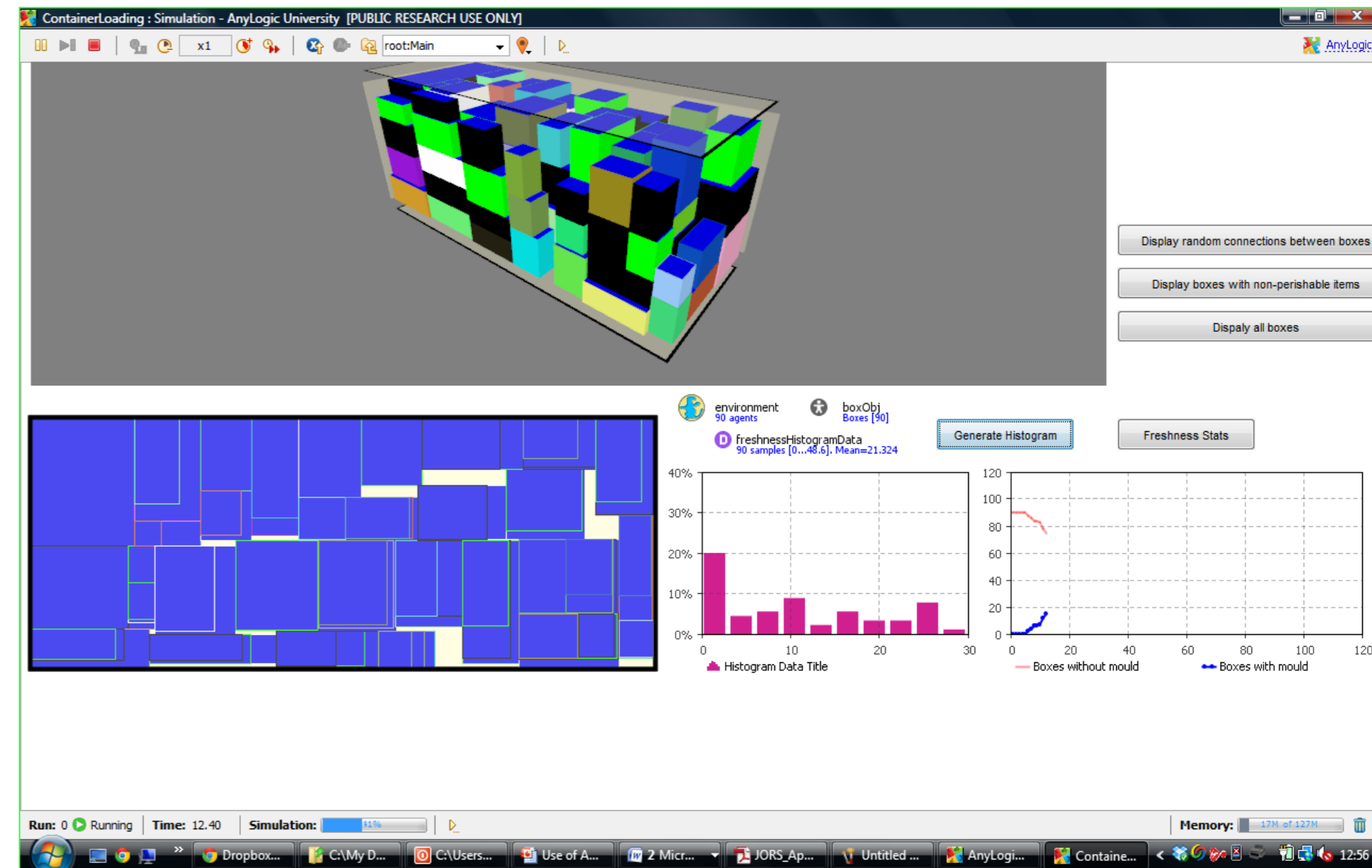
Cross-Contamination Model



Cross-Contamination Model



Cross-Contamination Model



Experiments

- Perishable items of goods and the three dimensional storage / transportation are assumed to be rectangular in shape and have known dimensions. The items ("boxes") are assumed to belong to different "box types".
- The predominant factor that distinguishes the various box types are the boxes' physical dimensions, i.e., length, breadth and height, and its **freshness index** (this index is a randomly generated value between 5 and 60).

Experiments

- Four benchmark problems, labelled **BTM20**, **BTM40**, **BTM70** and **BTM100**. Each represents a specific Box Type Mix (BTM) with 20, 40, 70 and 100 box types respectively. Thus it models both **weakly heterogeneous cargo** and **strongly heterogeneous cargo**.

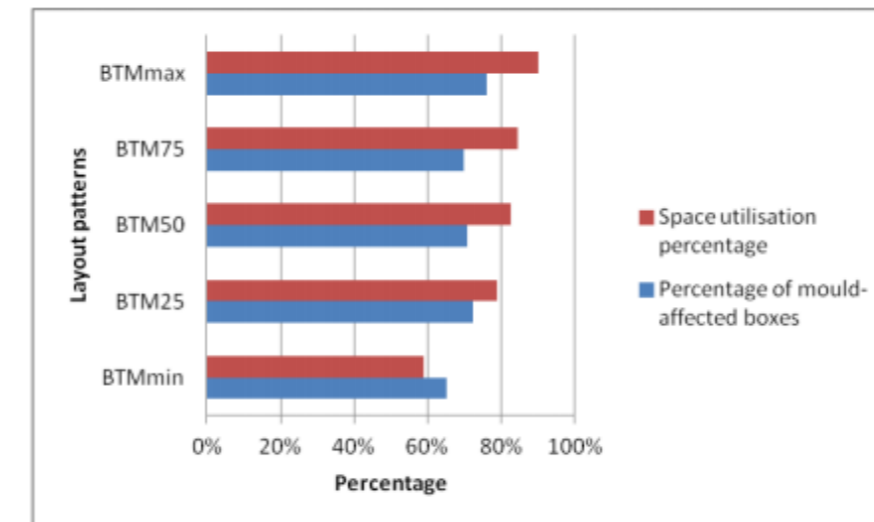
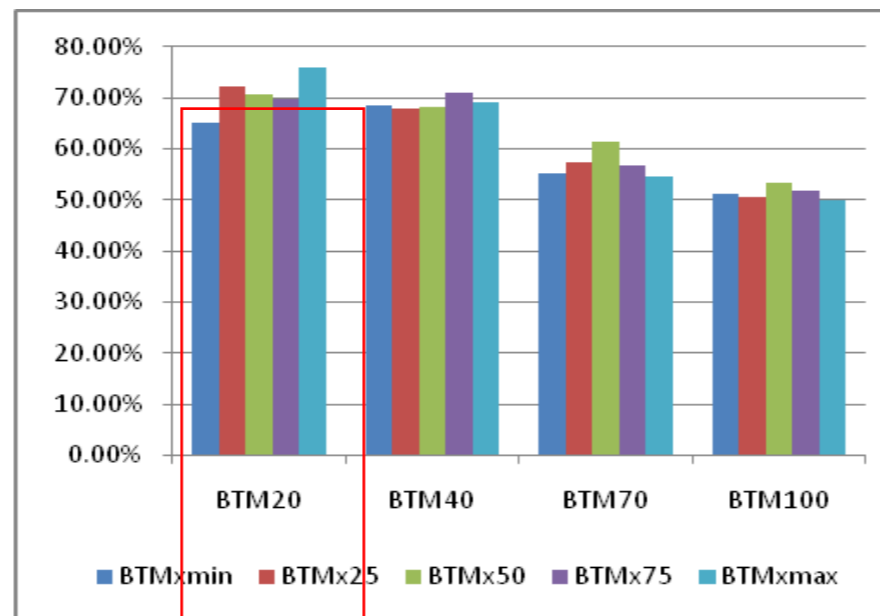
Experiments

- Using the CLA algorithm (**Bischoff, 2006**), 100 box layout patterns were generated for each BTM benchmark problem.
- For each BTM benchmark problem, five specific layout patterns were selected (where, x=20, 40, 70, 100):
 - (a) plan with the lowest space utilisation (**BTMxmin**)
 - (b) plan with the highest space utilisation (**BTMxmax**)
 - (c) plan with space utilisation percentile rank of 25 (**BTMx25**)
 - (d) plan with space utilisation percentile rank of 50 (**BTMx50**)
 - (e) plan with space utilisation percentile rank of 75 (**BTMx75**)

Percentage of affected boxes, grouped by BTM

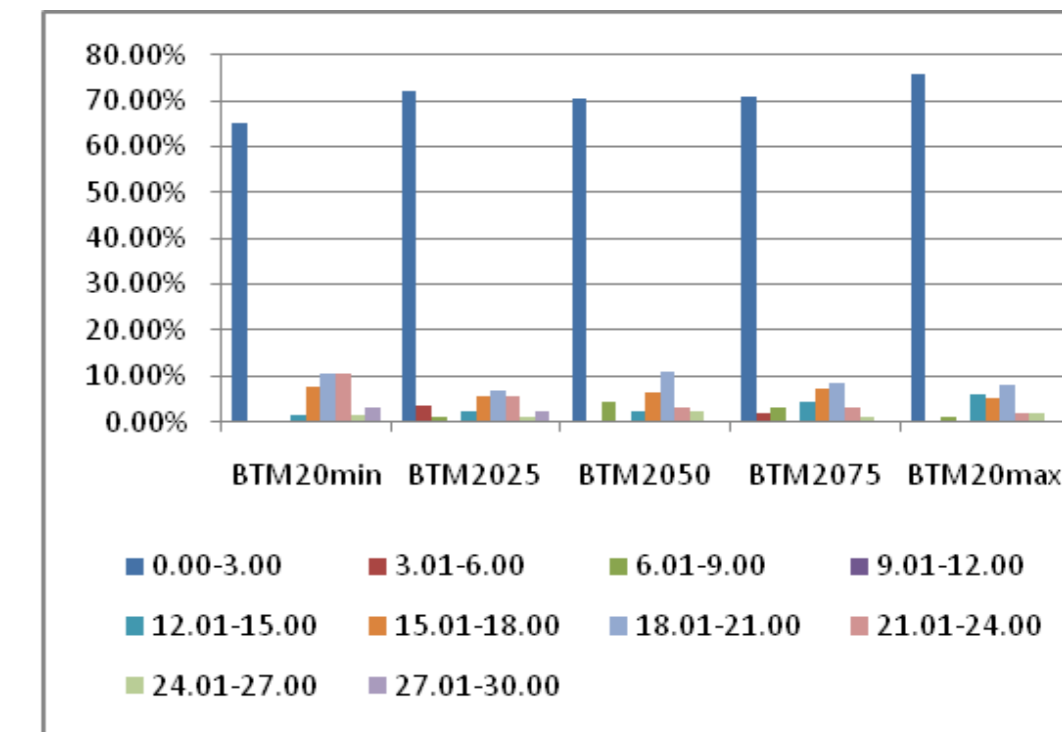
- We show the existence of trade-offs between space utilisation and the percentage of boxes affected with mould.
- BTM20 experiments: The five box layout patterns selected for simulation had the following utilisation efficiencies and proportion of mould-affected boxes.

Percentage of affected boxes, grouped by BTM



BTM20 experiment	Space Utilisation	% of Affected Boxes
BTMxmin	58.79%	65.15%
BTMx25	78.93%	72.22%
BTMx50	82.60%	70.65%
BTMx75	84.43%	69.79%
BTMxmax	89.94%	76%

Freshness % for BTM20 Benchmark Problem

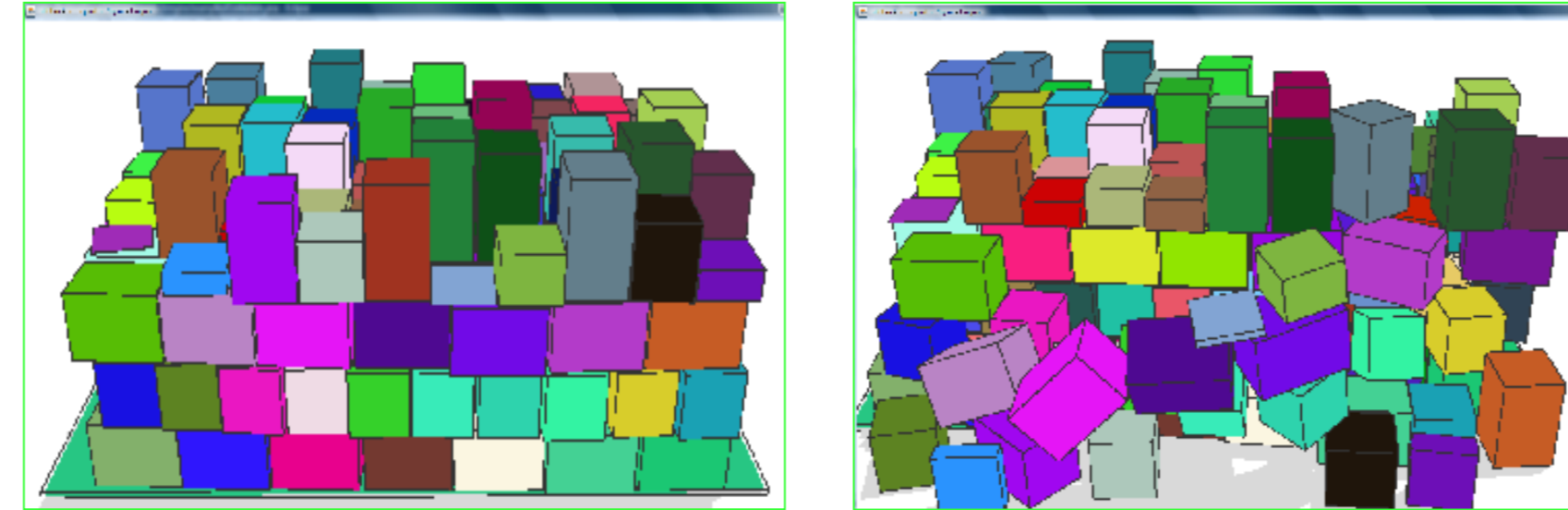


- For all five loading plans simulated, between 65 to 76% of items had already been affected but would be affected in the next three days (note the freshness/bin range: 0.00-3.00).
- If the *BTM20min* loading plan was selected, then approximately 33.33% of items will remain relatively fresh (bin/freshness range: 15.00 to 30.00) by the end of the 30-day simulation – and this value is at least 50% higher when compared to the corresponding freshness values of the alternate loading plans.

Conclusion

- The work presented in this paper has demonstrated the feasibility of using agents and CLA for modelling cross-contamination amongst such items.
 - In particular, it has focussed on items that are stored or transported in close proximity and are in physical contact.
 - The key is to find the trade-off between optimisation of storage and/or transport space and the probability of cross-contamination!
- This approach can be expanded to model analogous situations wherein physical proximity between agents is the necessary condition for inter-agent interaction. For example, spread of fire through hazardous materials.

Future Work



Simulation Time

Future Work

- Every box to be bestowed with the independent Newtonian motion properties
- Its motion will depend upon the box properties (e.g., dimensions and mass) and also on the other boxes surrounding it
- This may be accomplished through use of a physics engine (with capabilities for collision detection)
- CPO Algorithms + ABS + Physics Engine

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**Thank you for your
attention!**

Questions and Comments ...

n.mustafee@exeter.ac.uk

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