Using Ptolemy II as a Framework for Virtual Entity Integration & Orchestration in Digital Twins

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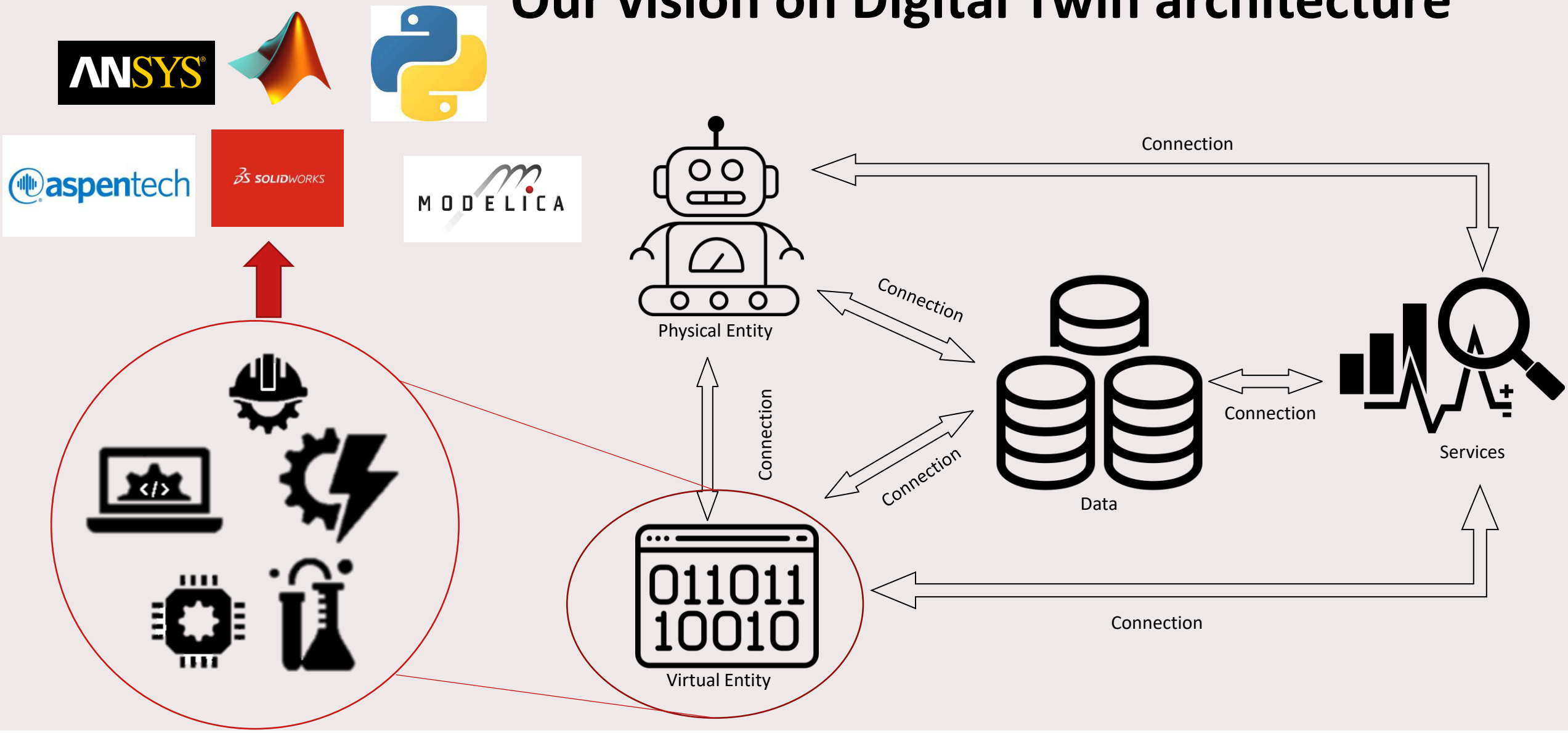
Agenda

- Problem definition
- Background
- Solution design – Ptolemy II implementation
- Results
- Conclusion & future work

Our vision on Digital Twin architecture



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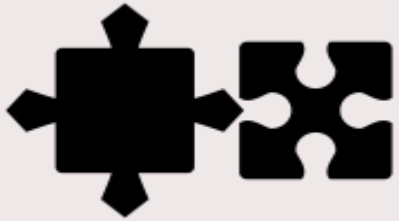
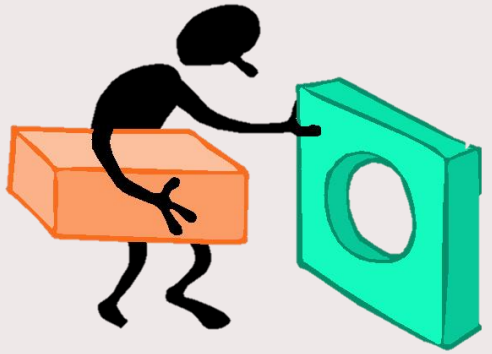
Problem definition

- Different **tools** have **different semantics and syntax**.



- **Manual integration** becomes **unfeasible**, automation is needed.



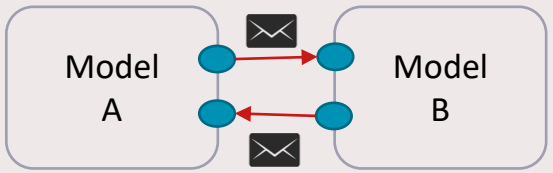
- A **framework** to **automate** the **integration** is required. Commercial options exist, but they only support their own tools for modeling.

Problem definition

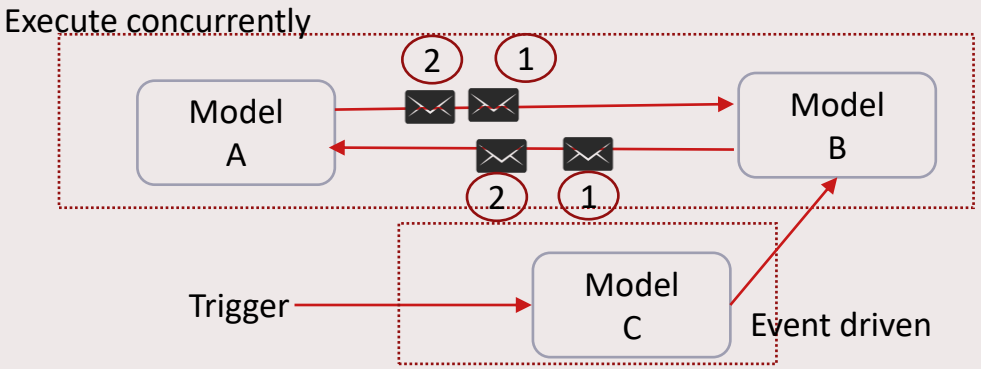
Our aim: Find a **framework** to **integrate heterogenous models** & **extend** it.

❖ **2 aspects** for integration:

- **Communication**: interface & encapsulation
- **Orchestration**: sequence of execution (control flow) and how data is exchanged (data flow)

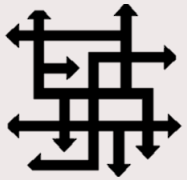


Communication

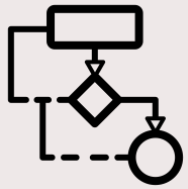


- Ptolemy II is a promising framework for integration.

Integration



Reduce Complexity



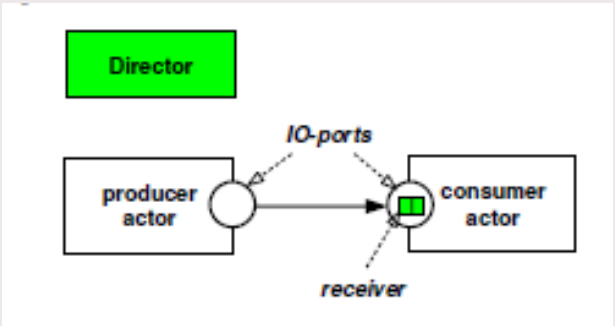
Reproduce behavior

Startup

TU/e

Background – Ptolemy II

- **Objective**: support analysis & experimentation with CPSes
- **Actor oriented**
- **Directors** are **orchestrators** of actors
- **Separated control flow and data flow**



Why Ptolemy II:

1. **Open-source**
2. Accessible and sufficient **documentation** & **support**
3. Artefacts are **modular & re-usable**

Background – AES-Lab [1]

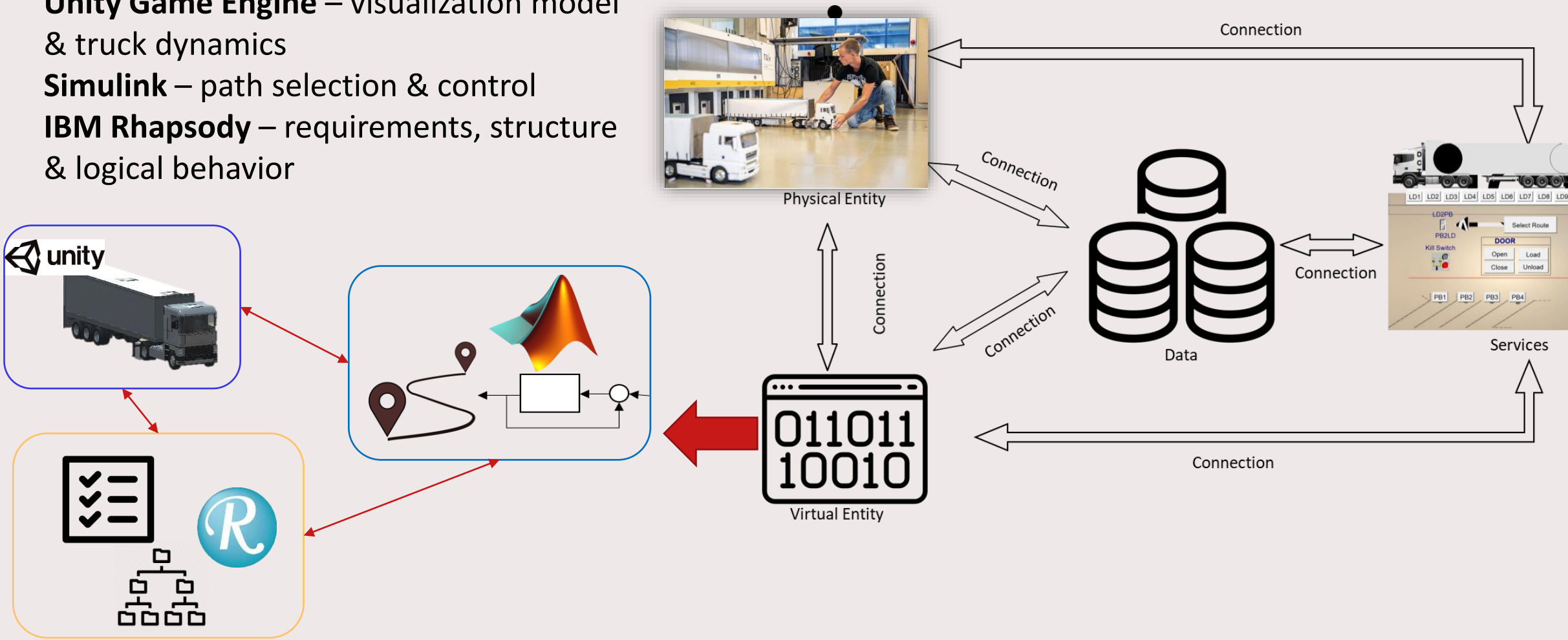
- **Scaled-down truck** for driving and docking in a DT.
- Used for **testing of autonomous driving**: path generation, avoidance of obstacles & driving control.

[1] Barosan, I., Basmenj, A. A., Chouhan, S. G., & Manrique, D. (2020, September). Development of a Virtual Simulation Environment and a Digital Twin of an Autonomous Driving Truck for a Distribution Center. In *European Conference on Software Architecture* (pp. 542-557). Springer, Cham.

AES-Lab Digital Twin

Models:

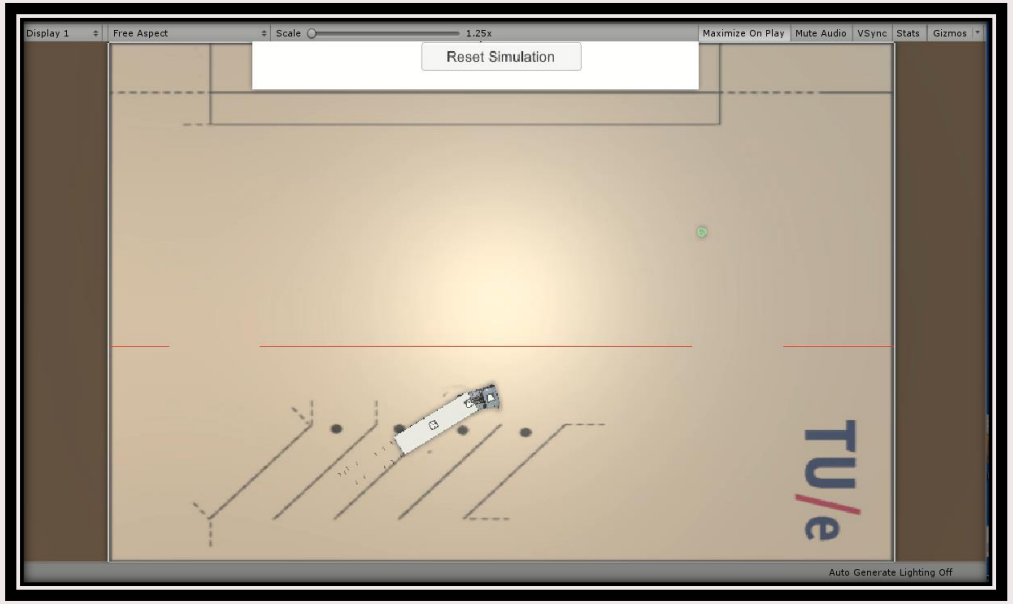
1. **Unity Game Engine** – visualization model & truck dynamics
2. **Simulink** – path selection & control
3. **IBM Rhapsody** – requirements, structure & logical behavior



Final behavior results

Use case for validation:

1. Truck at **initial position**.
2. Signal a **docking station** as **destination** for truck
3. Truck **generates a path.**
4. Truck **follows path**, **avoiding obstacles** & with **similar maneuvers** (speed & steering) as in [1].



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Original implementation vs our objective

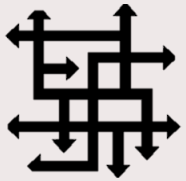
Implementation in [1]:

- Starting the execution **requires manual setup** & startup.
- **Complex Integration** between models.

Our implementation aims:

- **Decrease complexity** of integration, set-up & startup.
- **Reproduce** original **behavior.**

Integration



Reduce Complexity

Reproduce behavior

Startup

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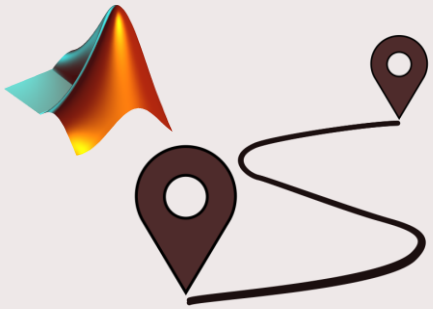
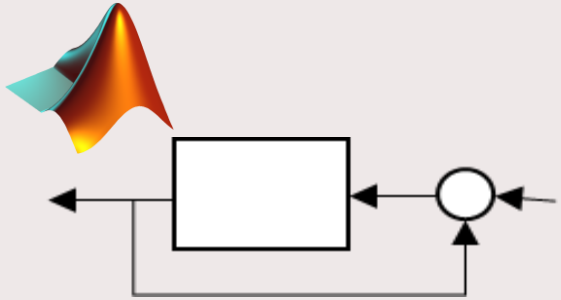
First steps for implementing of DT in Ptolemy II

Simulink models were split:

- To test director execution & model integration.



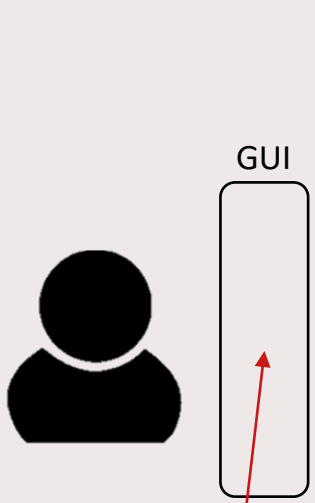
Path planner

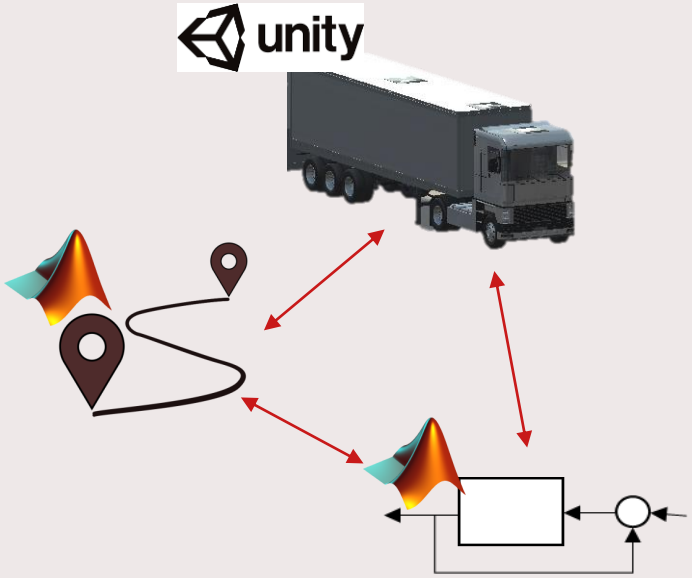


Control

- In a real application the separation would aid maintainability.

Integration of models:





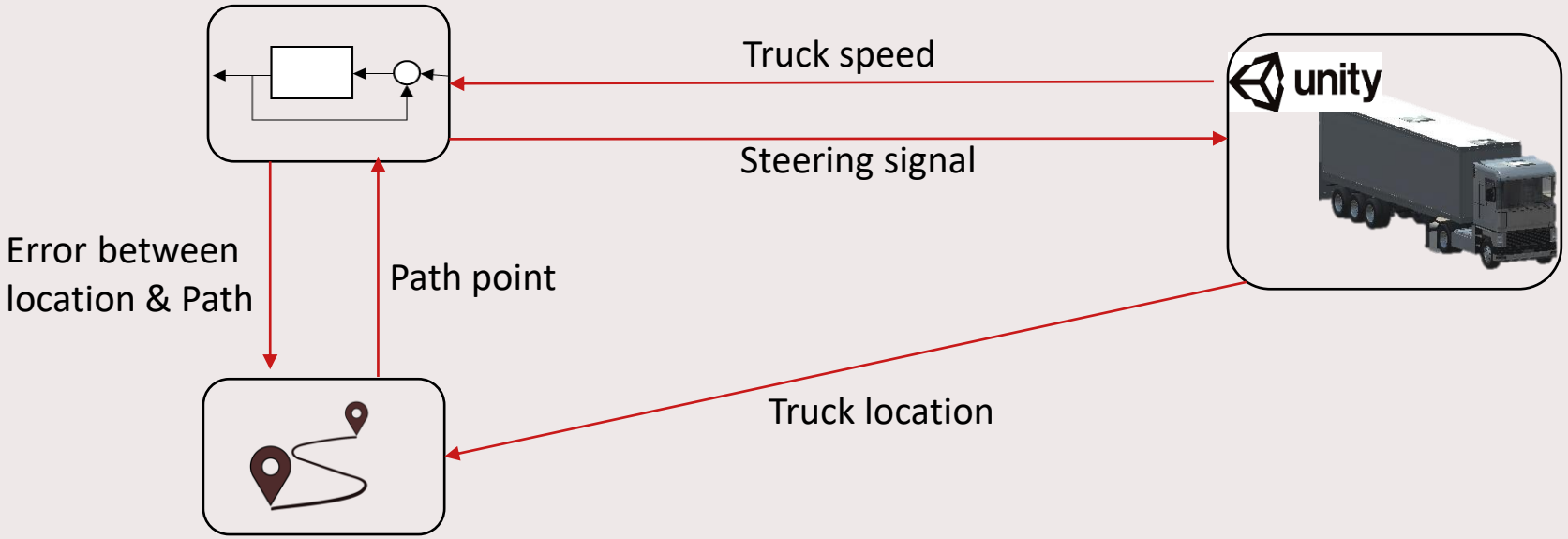
- Choose final destination
- Start truck movement

Ptolemy II Implementation - Actor

REQUIREMENTS:		Our Solution:
R1	Execution of all the models	Selected **Simulink actor** for Simulink models & **Exec actor** for Unity models.
R2	Simulink simulation state visible	New **Simulink actor**: • **Reduction of complexity** to call Simulink models. • **Enable visibility** on simulation states.
R5	Reduction of complexity in integration & setup	
R3	Model's communication on each time-step	**S-function** generation for Simulink models & **communication** over TCP-IP using **Python actor.**
R4	Enable configuration of Simulink solver (time-step)	Simulink actor **enables configuration** of Simulink **time-step.**

Ptolemy II Implementation - Orchestration

All models required **concurrent exchange & execution** of data

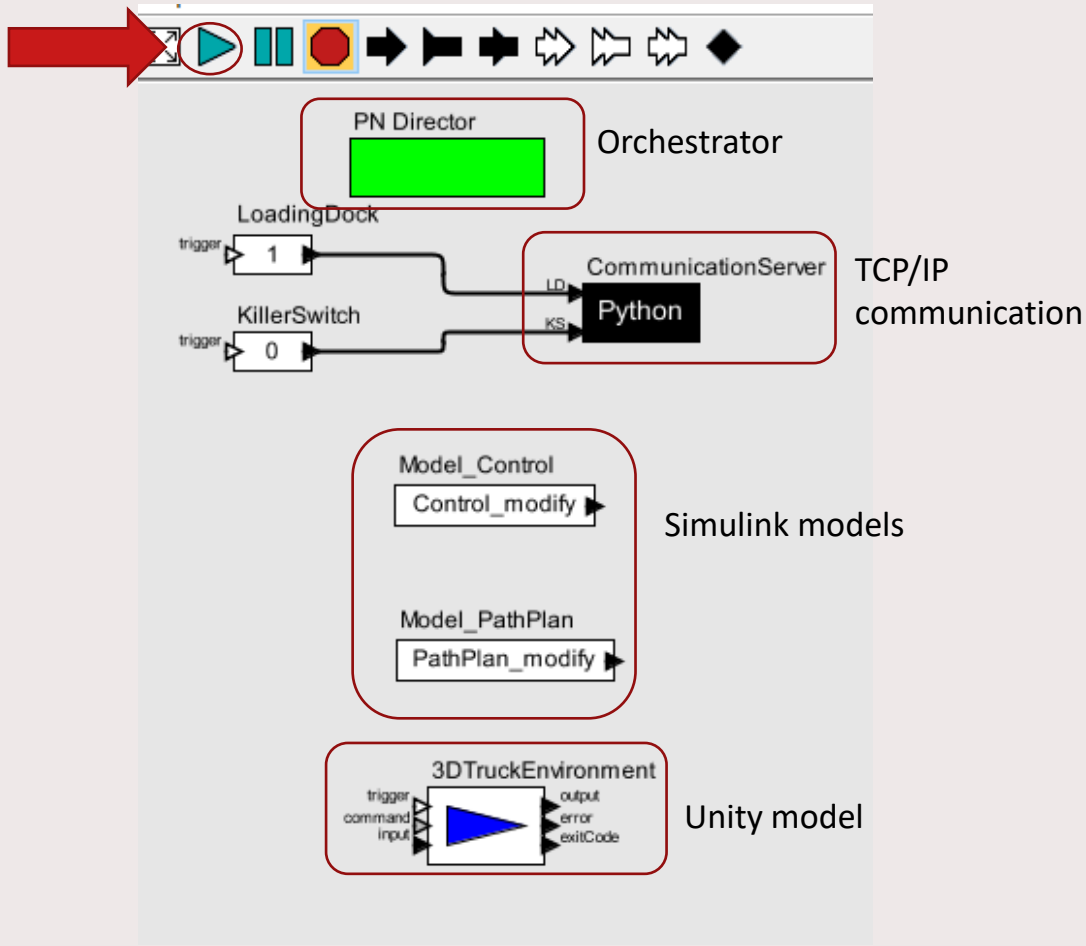


Our implementation → **PN director** for orchestration
Communication → **TCP/IP protocol** with python actor

Results - Analysis

Results: successful execution

- Decreased complexity of integration:
  - **Simulink** actors execute models with **only 2 parameters**
  - **Unity models** executed with **1 parameter**
- Reproduced original behavior:
  - Using **TCP/IP communication**
  - Orchestration of all models by **PN director**
- Setup and startup **complexity reduced**:
  - **One click** to start execution



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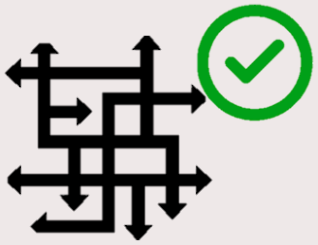
Conclusions

- Ptolemy II **facilitates models' integration**.
- **Actors reduce complexity** of such integration & aid **scalability**.
- **Director** can **orchestrate** control flow to **reproduce DT behavior.**
- **Simplified startup**.

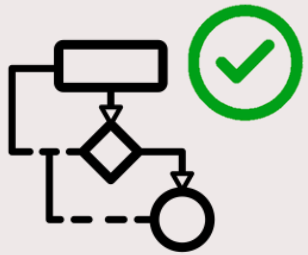
Future work

- **Implement data flow** control for orchestrator - Implement the data exchange within the **Simulink actor**.
- **Simplify further** the **integration** for Simulink models **- Automate** the generation of **S-function** for Simulink models.
- Experiment **on integration technologies** for other type of models, e.g., FMI.

Facilitate Integration



Reduce Complexity



Reproduce behavior

Simplified Startup

Thank you.