

TwinEco: A unified framework for dynamic data-driven digital twins in ecology

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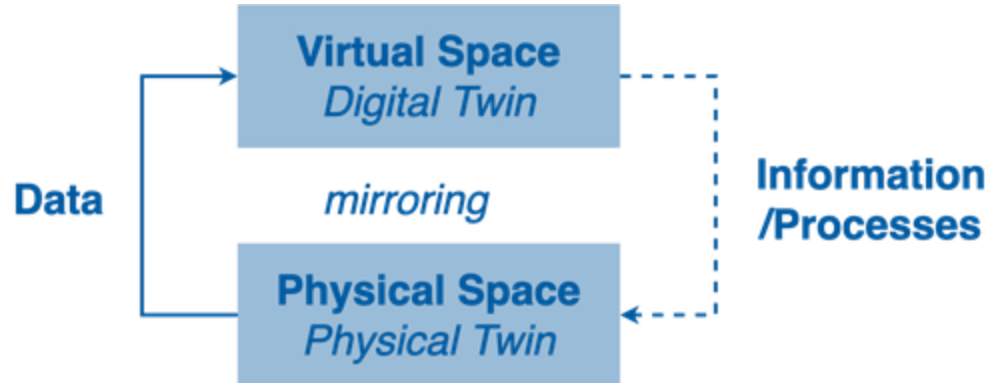
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03.03.2025 – BioDT School and Hackathon 2025

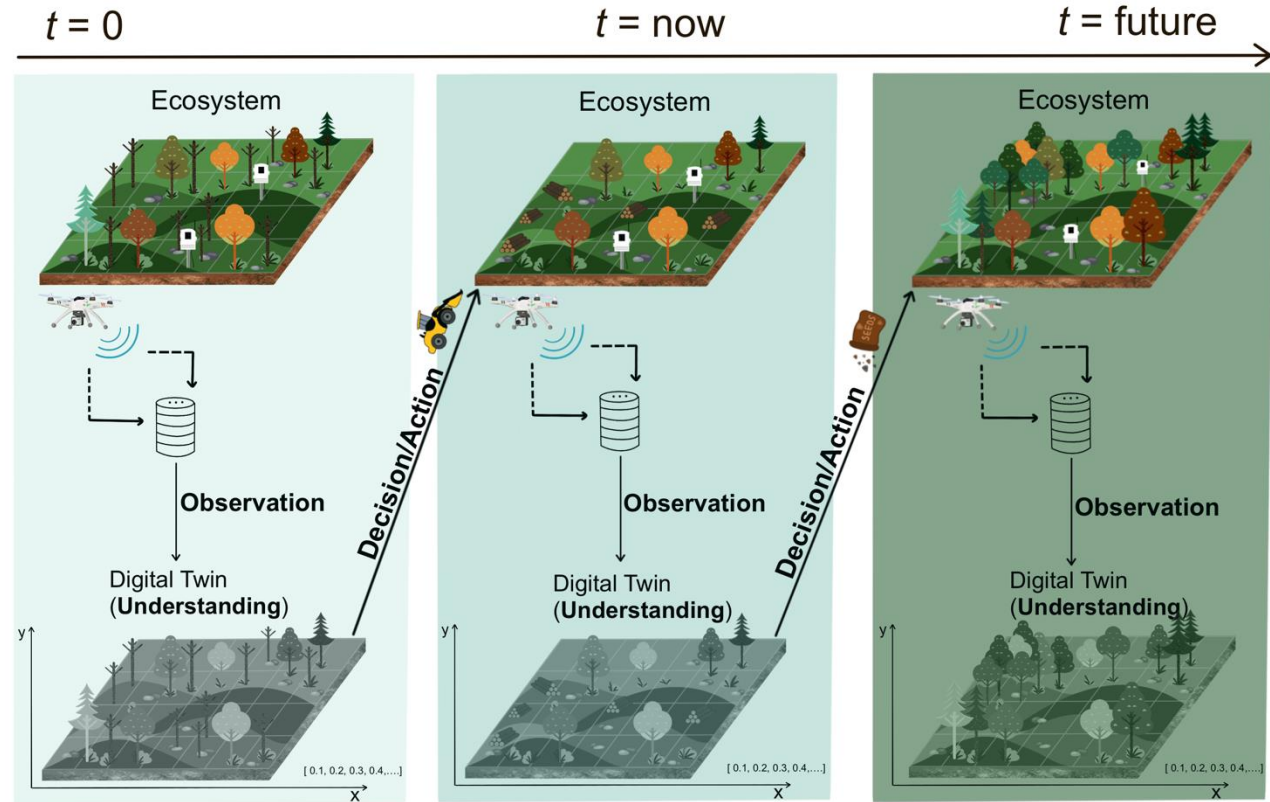
Defining Digital Twins

A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified **frequency** and **fidelity**.

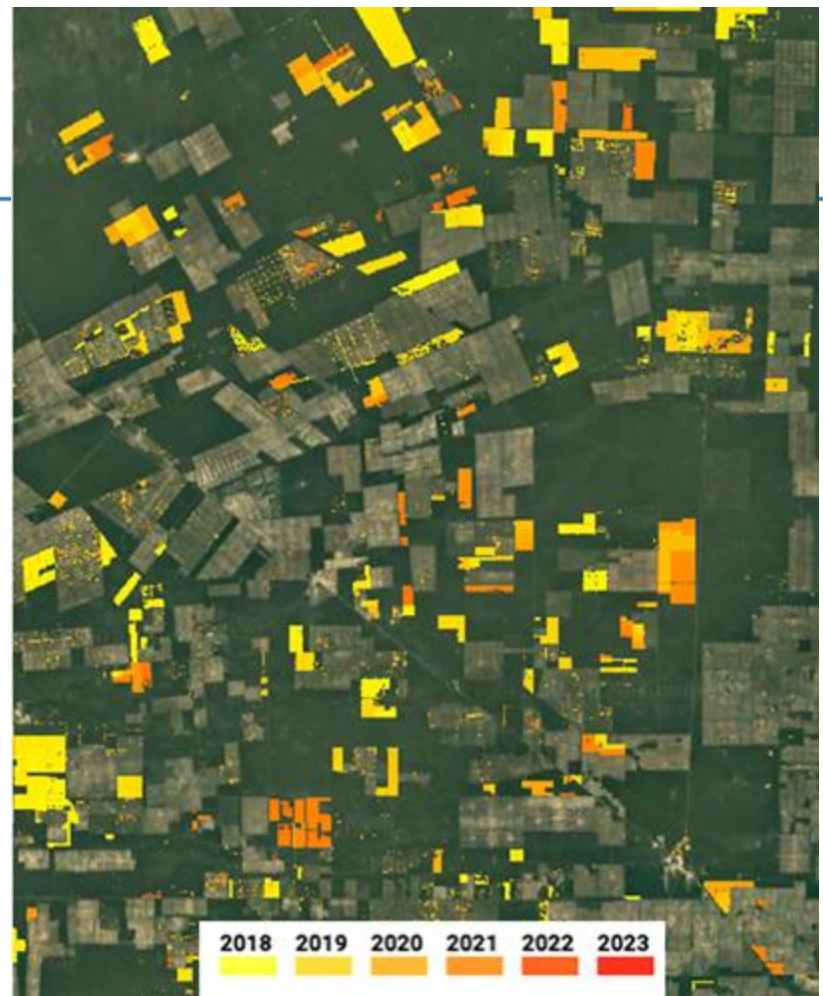


Defining Digital Twins

A DT combines the processes of **observation**, **understanding** and **decision/action**

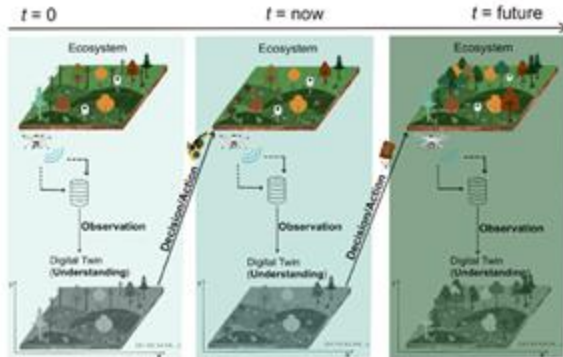
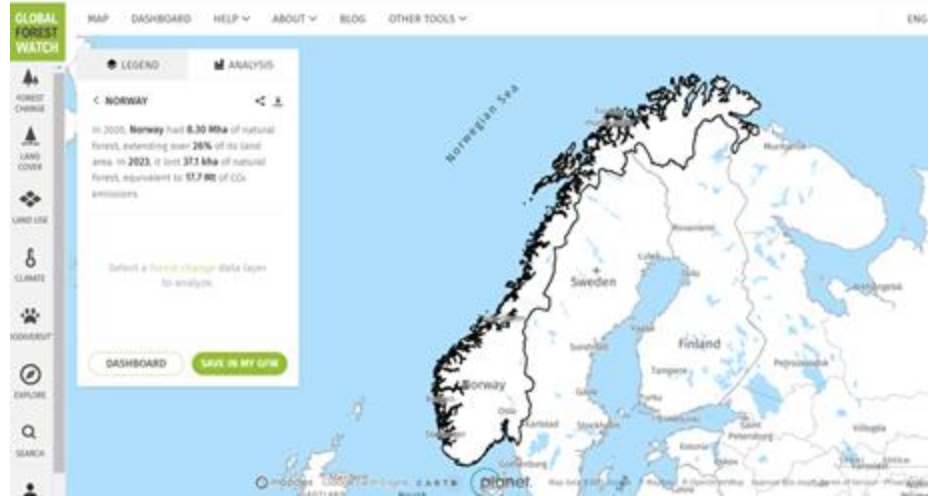
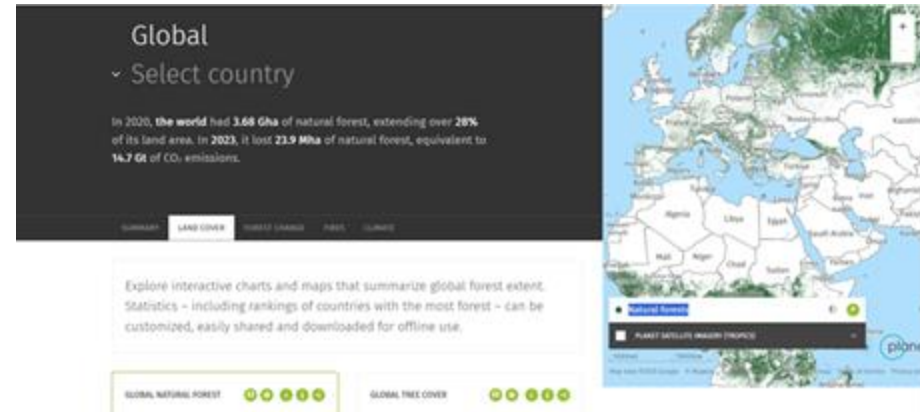


- **CTree:**
 - Tracks **land use changes** in near-real-time.
 - Focuses on **deforestation** and **forest degradation**.
 - Monitor forest disturbances in near real time
 - Disturbances due illegal logging, forest fire etc
 - Uses **Sentinel-1 (radar)** and **Sentinel-2 (optical)** satellite data for accurate monitoring.
 - Alerts:
 - Generates **alerts** for detected changes every other week.
 - Alerts can be received via **email, SMS, or dashboard**.
 - Helps stakeholders respond quickly to illegal logging or forest loss.

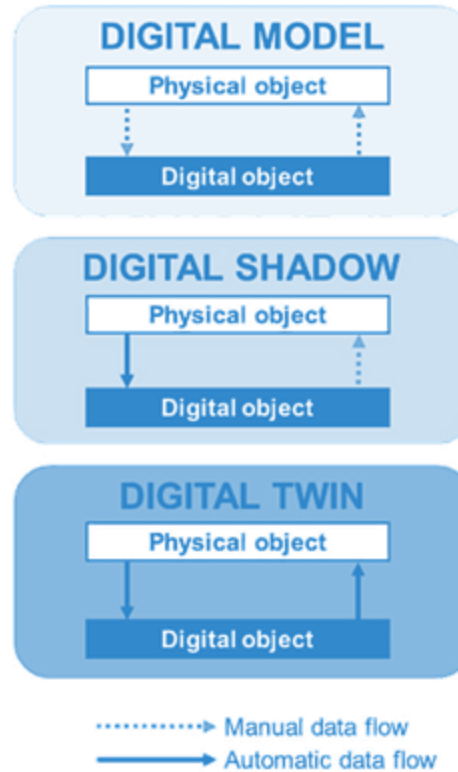


Example

- Global Forest Watch (GFW)
 - Tracks **deforestation**, **forest degradation**, and **land use changes**.
 - Provides **near-real-time data** on tree cover loss, fires, and biodiversity threats.
 - **Frequency of Updates:**
 - **Daily** (forest fires)
 - **Weekly/Monthly** (deforestation alerts)

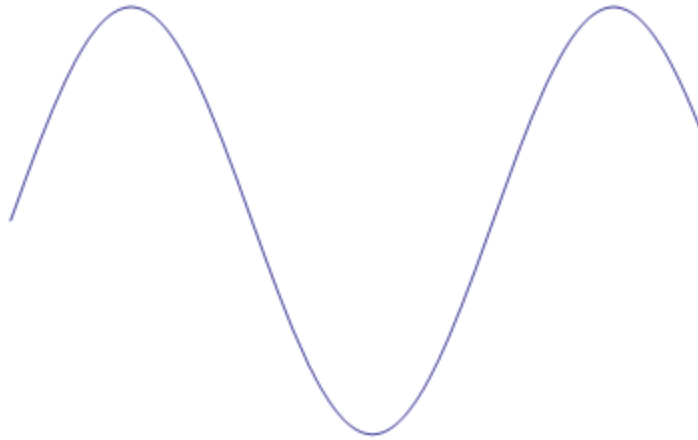


Digital Twins in Engineering



How to conceptualise Digital Twins?

Digital Twins are dynamic, they move and change over time.





New Results

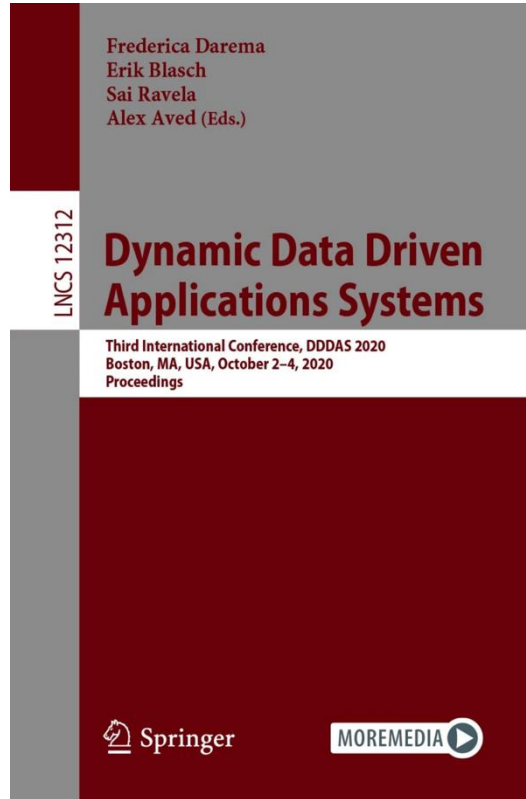
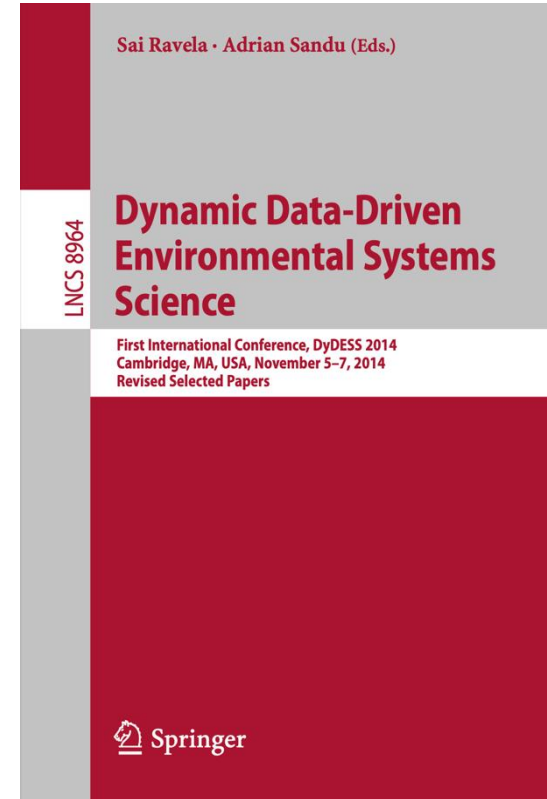
TwinEco: A Unified Framework for Dynamic Data-Driven Digital Twins in Ecology

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doi: <https://doi.org/10.1101/2024.07.23.604592>

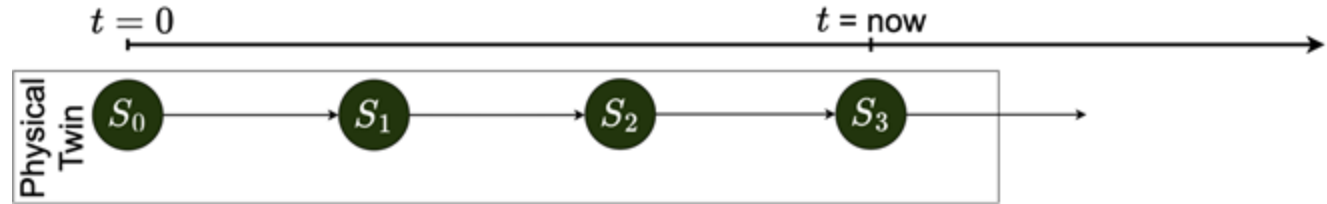
This article is a preprint and has not been certified by peer review [what does this mean?].

Dynamic Data Driven Application System



TwinEco Layers

Physical State, S:
Parameterized state
of the physical asset



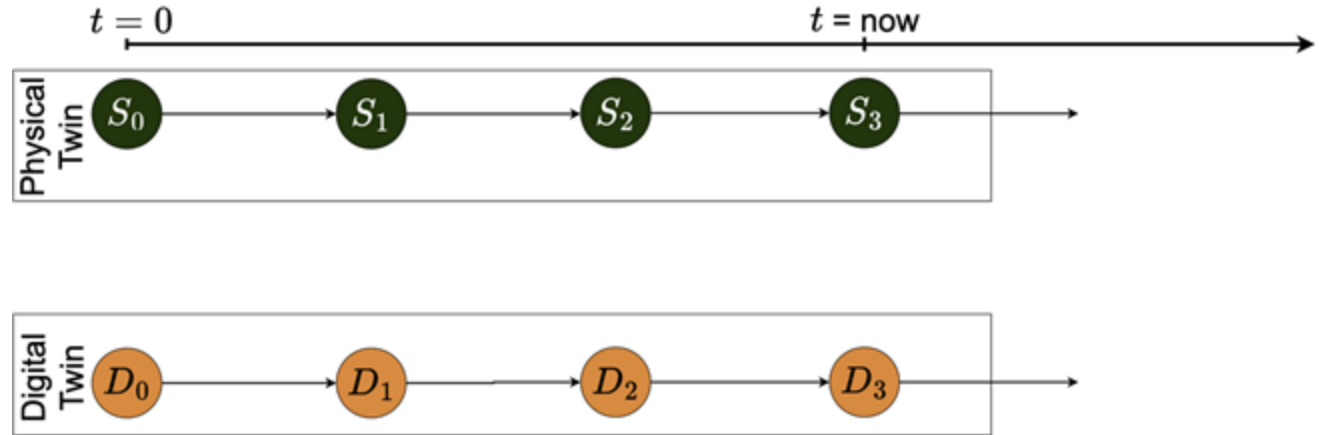
TwinEco Layers

Physical State, S :

Parameterized state of the physical asset

Digital State, D :

Parameters (model inputs) that define the computational models comprising the digital twin

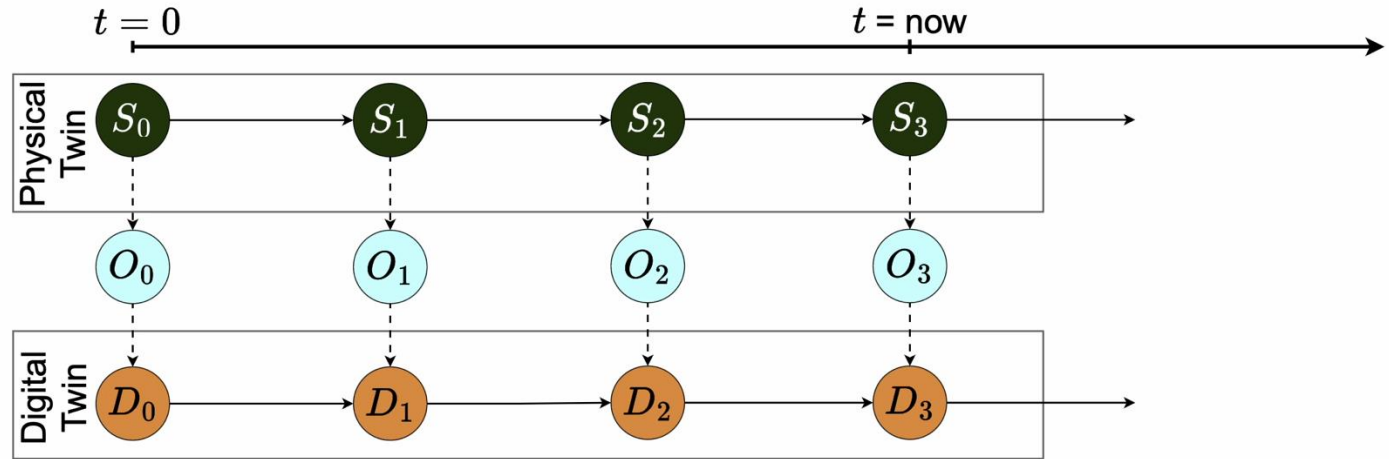


TwinEco Layers

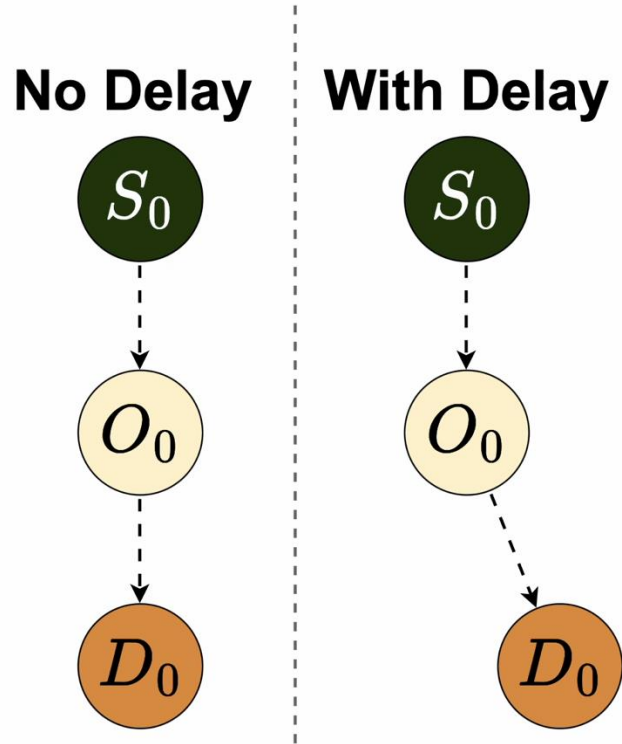
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**Observational
data, O :** Available
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describing the state
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Temporal Delay

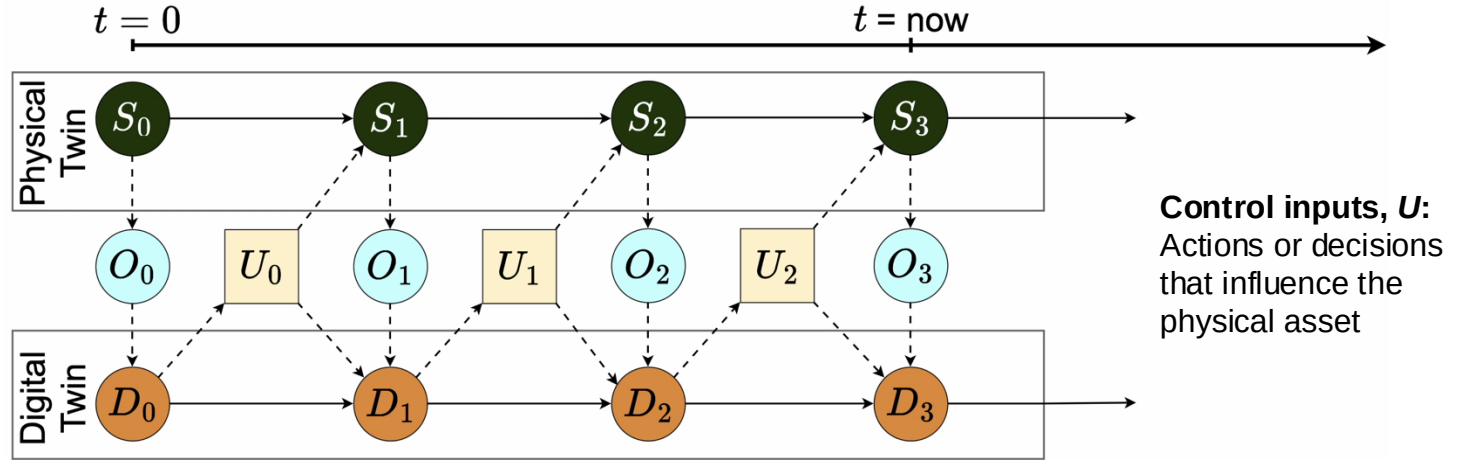


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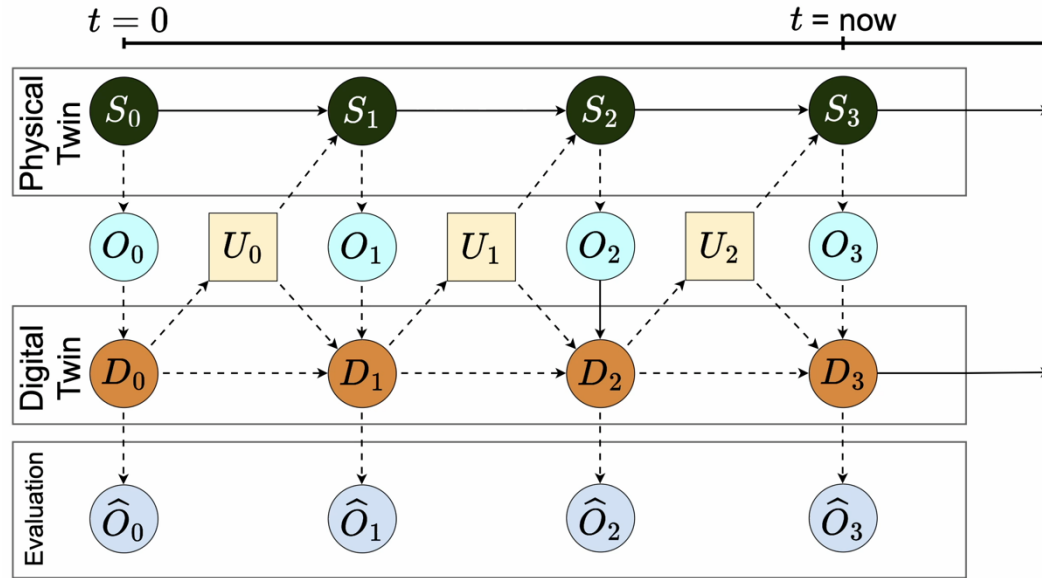


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Control inputs, U :
Actions or decisions
that influence the
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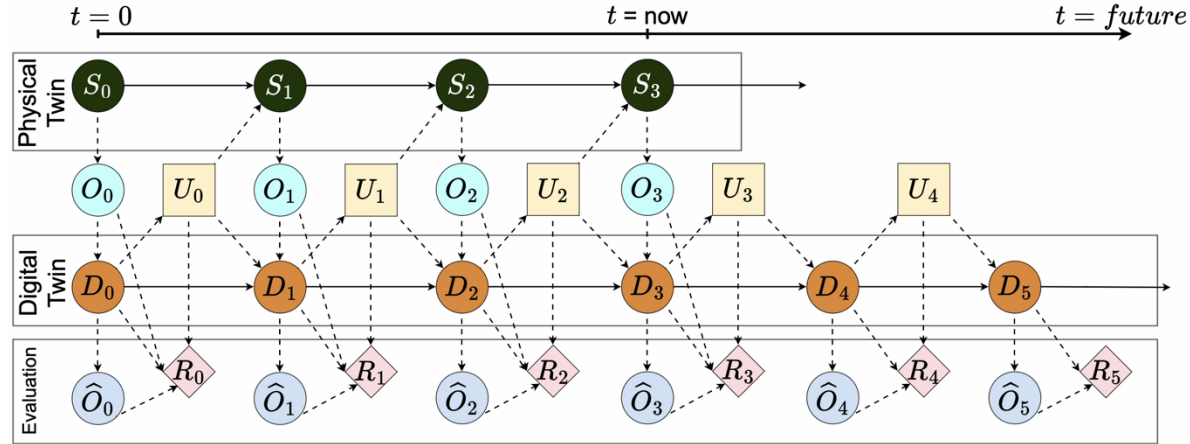
Evaluation, $\hat{O}$:
Evaluation of the
Digital State derived
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Data

TwinEco Layers

Physical State, S :
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Control inputs, U :
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Evaluation, $\hat{O}$:
Evaluation of the Digital State derived from Observational Data

Reward, R :
Quantifies preference of different states or trajectories of the asset-twin system

TwinEco Components

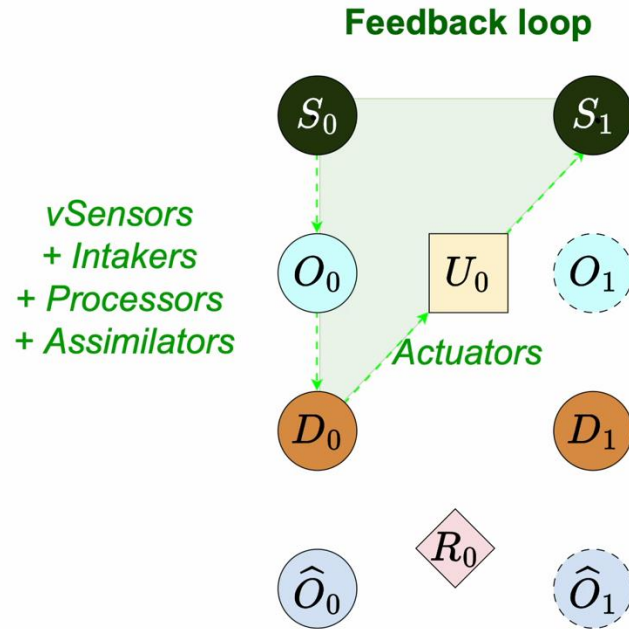
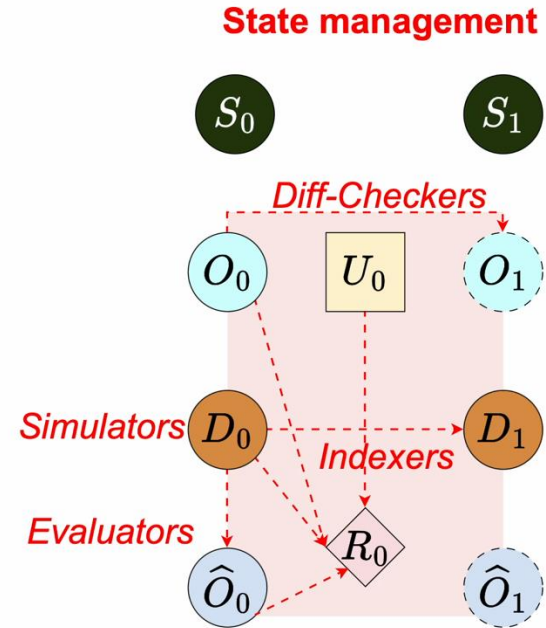
Feedback Loop

- **vSensor** – Detect changes in data sources.
- **Intaker** - Pull new data.
- **Processor** - Process the data.
- **Assimilator** - Assimilate the data into existing datasets.
- **Actuator** - Change control inputs.
- **Logger** - Log events.

State Management

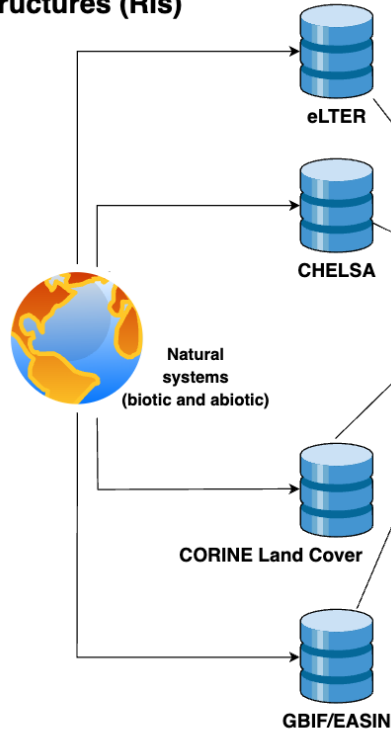
- **State Space** – The definition of input and output parameters of simulators.
- **Simulator** - The model/s behind the DT.
- **Indexer** - Index the state space over time.
- **Diff-Checker** - Describe differences in state space over time.
- **Evaluator** - Evaluate the outputs of the simulators and update the reward values.

Mapping Components to Layers

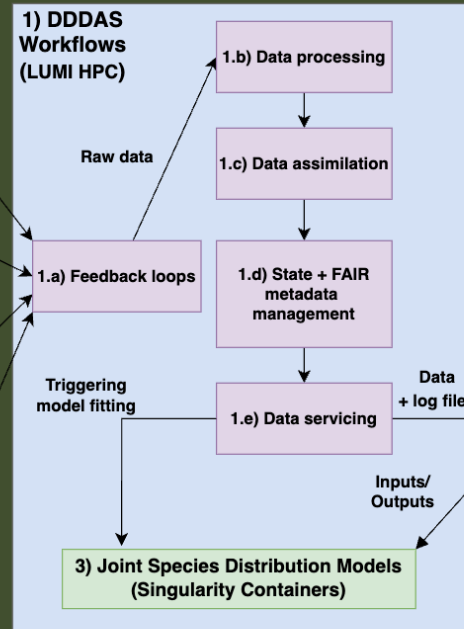


Use Case: Invasive Alien Plant Species DT

Data sources and Research Infrastructures (RIs)



Invasive Alien Species prototype Digital Twin (IAS pDT)



Exercise – Your turn!

- Time to test your understand of DTs.
- Create 3 groups for this exercise.

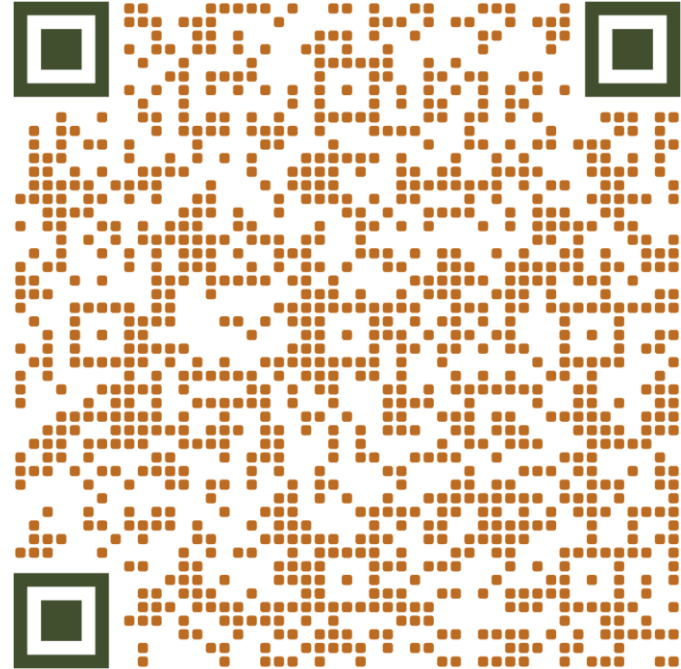
Goals

- Pick any ecological process or object that your group would like to create a DT for (*e.g. forest growth, bird monitoring, phenological change etc.*)
- Create an architectural diagram of your DT as a conceptual exercise.
- Use and incorporate the TwinEco framework as much as possible.

Hint: Start by thinking about what are the different layers of your DT and then what components would be needed to build the dynamics between those layers? You can choose to go into as much details as you would like.

Instructions

- Scan the QR code to open the drive folder for the exercise.
- Make a copy of the **twineco.drawio** file in the same drive folder
- Work on your file using the online draw.io tool or locally and save it back on the drive!
- Groups present their DT architectures in 5 min presentations.



Thank you!



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