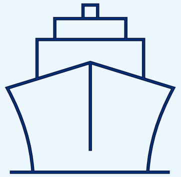
Accuracy and assurance in co-simulations

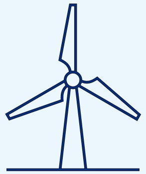
A global assurance and risk management company

160	~15,000	~100,000	100+	5%+
years	employees	customers	countries	of revenue in R&D

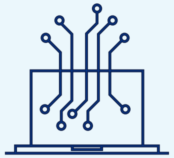
Ship and offshore classification and advisory



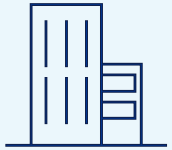
Energy advisory, certification, verification, inspection and monitoring



Software, cyber security, platforms and digital solutions



Management system certification, supply chain and product assurance



DNV

Simulation Technologies

Group Research & Development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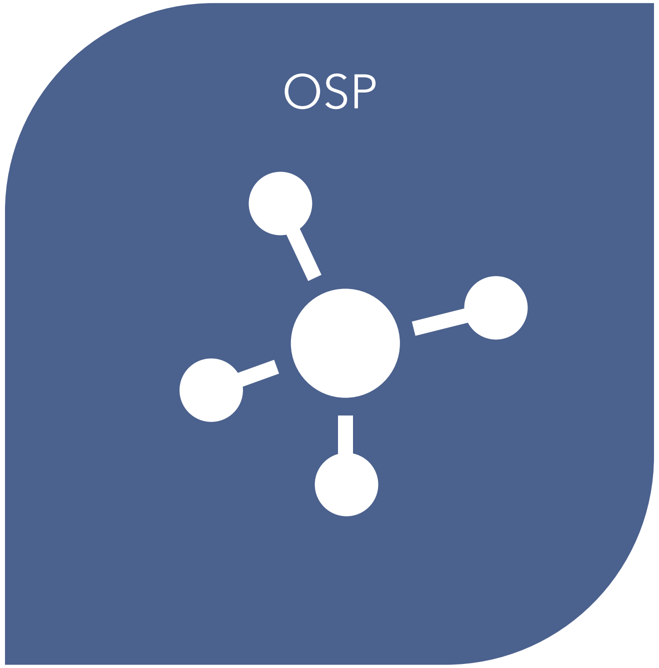
Industry needs

Build scalable and trustworthy system simulations of complex, integrated designs:

- Re-use simulation models collaboratively.
- Protect individual IP.
- Ease common hurdles, such as coupling.
- Establish trust in models.
- Shift assurance left.

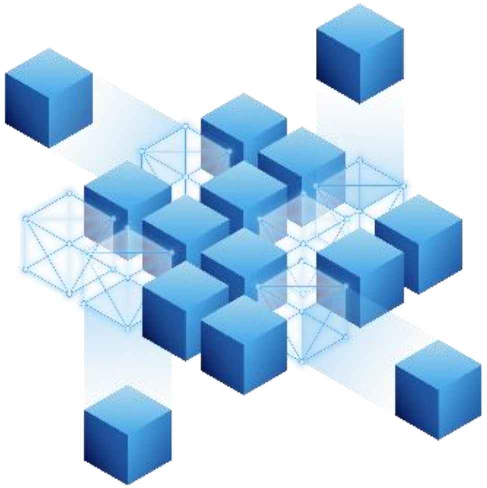
https://www.flickr.com/photos/vancouver125/5834658432/

Open standards - Integrated technology



Open Simulation Platform
https://opensimulationplatform.com

STC



Simulation Trust Center
https://store.veracity.com/simulation-trust-center

Modularity – Interoperability

Model Assurance

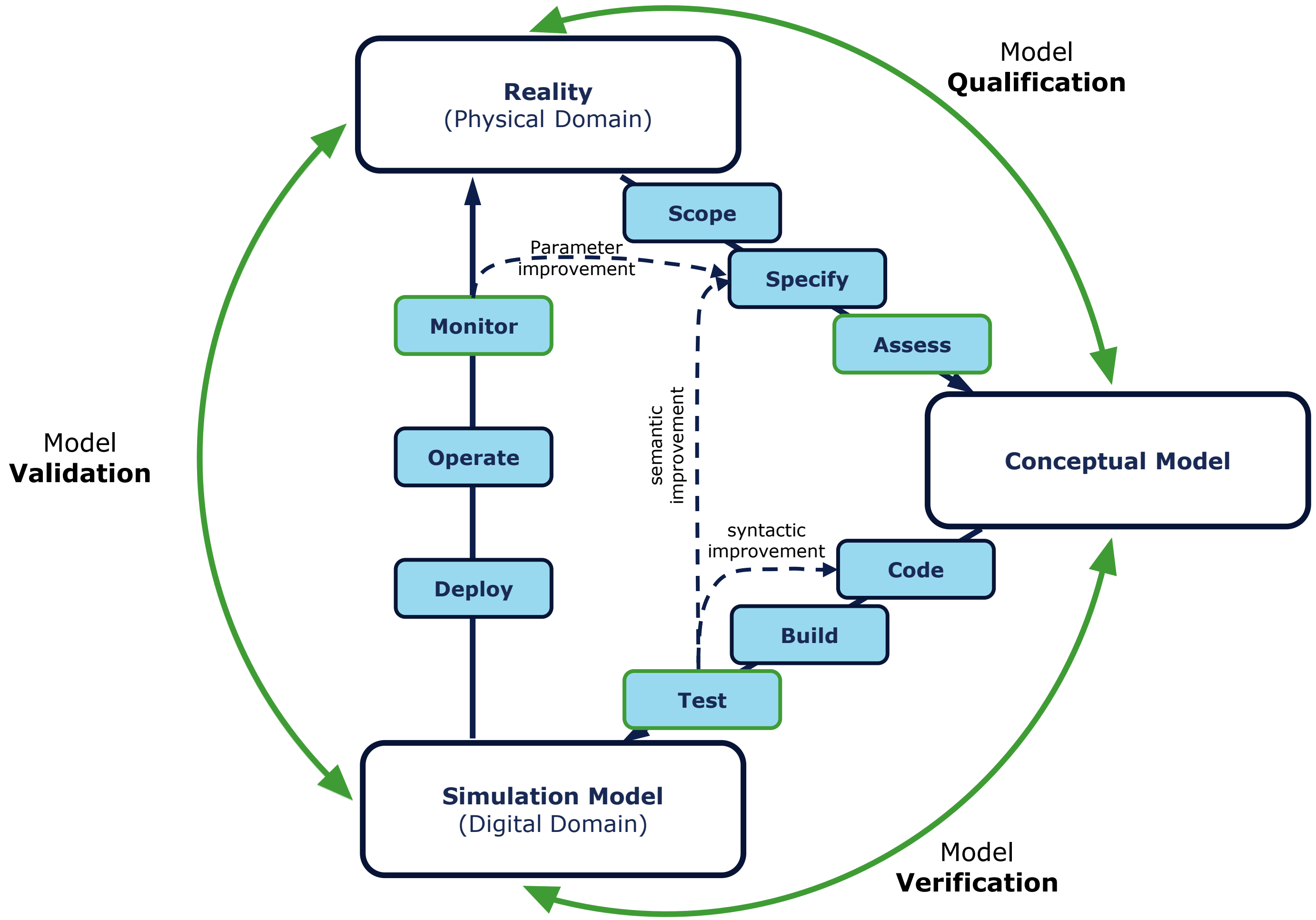
Model Assurance

- Trust in decision support ← trust in models
- Model confidence level dependent on risk that the model is fooling the user
- Assurance activities adjusted to the model confidence level
- DNV-RP-0513 *Assurance of simulation models*
- DNV-RP-0671 *Assurance of AI-enabled systems*

		Reality	
		possible	impossible
Simulation Model	does not work	risk	ok
	works	ok	high risk

*“Assurance […] involves constructing an assurance argument consisting of **claims** […] substantiated by **evidence**”*

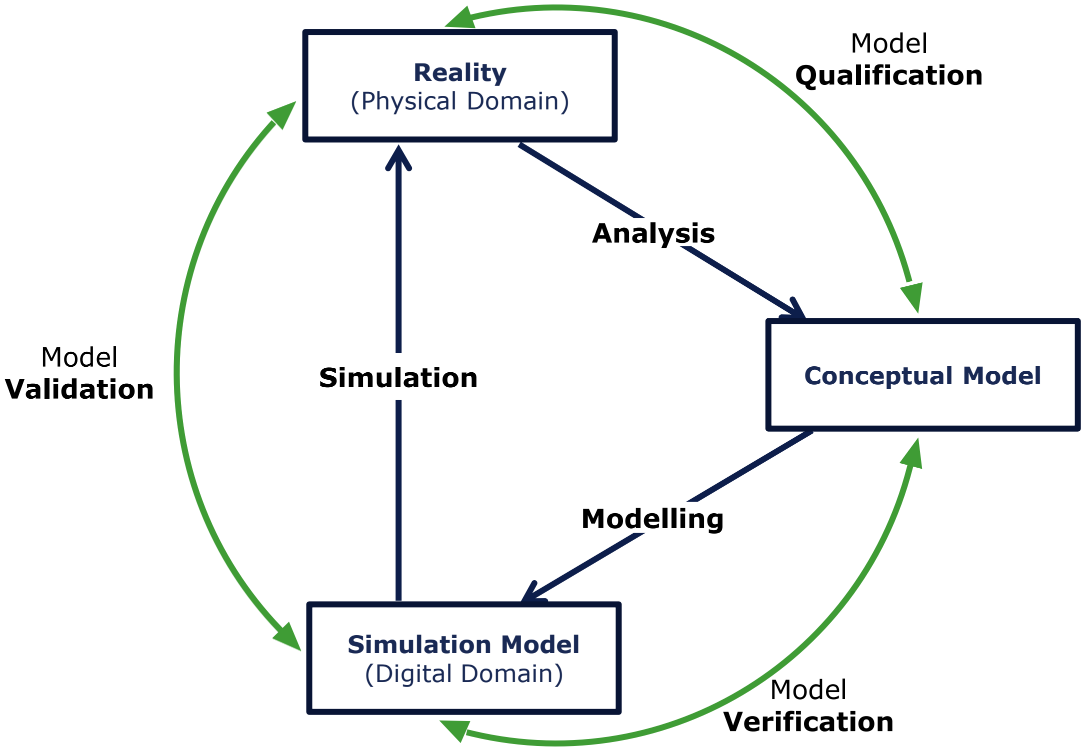
Model Assurance: Integrates in Model Lifecycle



RP-0513 Assurance of Simulation Models

3.3.4 Model validation

- A. Validation activities
- B. Validation test methods
- 2.3.4 Design Contract



3.3.2 Conceptual Model qualification

- 3.3.2 Conceptual Model checklist
  - 2.6 Risk Analysis
  - 2.6.4 Confidence Level
  - 2.6.5 Maturity Level
  - 2.5 Modelling Types
- 3.2 Supplier Assurance
- 2.3.4 Design Contract

3.3.3 Model Verification

- A. Verification activities
- B. Test Methods
- C. Static Model analysis
- 2.6 Detailed risk analysis

Conceptual model specification (DNV-RP-0513)

Objective	• Identify the goal for the model • Describe intended use cases
System boundary	• Define what external phenomena's the model will deal with • Define internal physics / functionality • Define input and output data
Require-ments	• Define requirements to the model (accuracy, max computational time, valid input ranges, etc.) • Data quality requirements • How to report model quality indicator (operating outside its qualified range or other issues that may impact the output quality)
Modelling concept	• Identify suitable modelling concept / techniques to achieve objective • Define model modularisation and hierarchy • Identify available components models
Assump-tions	• Identify high-level assumption and limitations • Required input data for validation and related data quality
Risk analysis	• Identify risks that may result in the model providing incorrect or inaccurate results • Identify the confidence level
Validation	• Requirements to verification & validation plan • Identify suitable data for model development and testing • Gather validated results that the simulation model can be validated against

Capture

Design contract

Risk Assessment

	Severity of consequence if function does not work as intended			
	Minor	Significant	Severe	Catastrophic
High uncertainty that model does not represent relevant aspects of the reality	2	3	4	Not Trusted
Medium uncertainty that model does not represent relevant aspects of the reality	1	2	3	4
Low uncertainty that model does not represent relevant aspects of the reality	0	1	2	3

Uncertainty

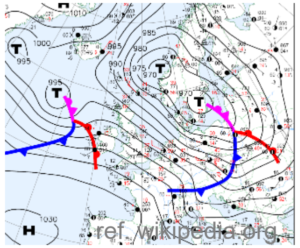
Severity of Consequence

Uncertainty-shaping factors

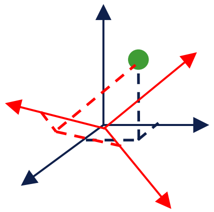
- Strength of knowledge
- Model size
- Model complexity
- Modelling variability
- Design novelty
- Application novelty
- Input data accuracy
- Numerical accuracy

SeaCo
Safer, more reliable, and accurate co-simulations

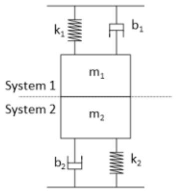
SeaCo – managing modularization challenges



WP1 Standardized environmental modelling

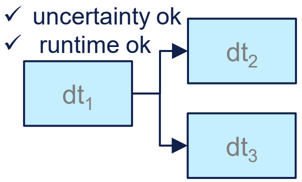


WP2 Coordinate system transformations



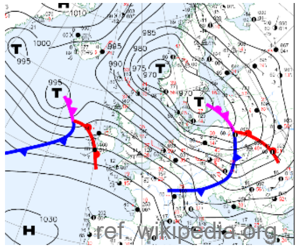
WP3 Modular tightly coupled systems

WP5 Testing and verification

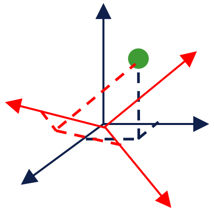


WP4 More accurate and reliable co-simulations

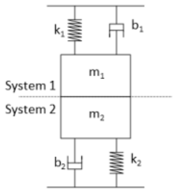
SeaCo – managing modularization challenges



WP1 Standardized environmental modelling

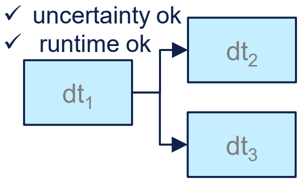


WP2 Coordinate system transformations



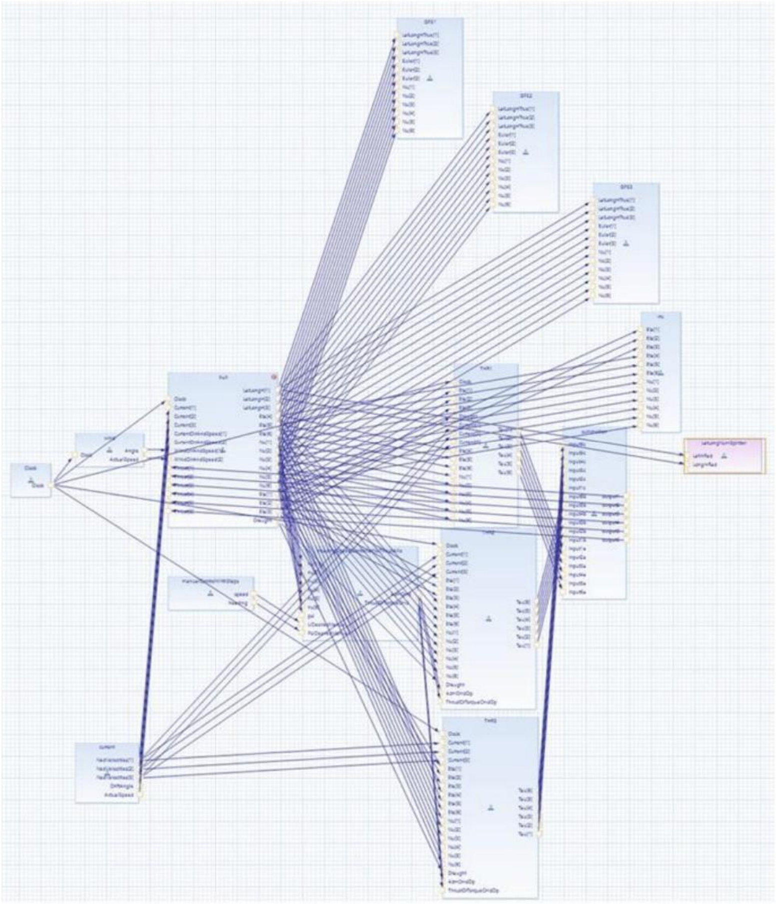
WP3 Modular tightly coupled systems

WP5 Testing and verification

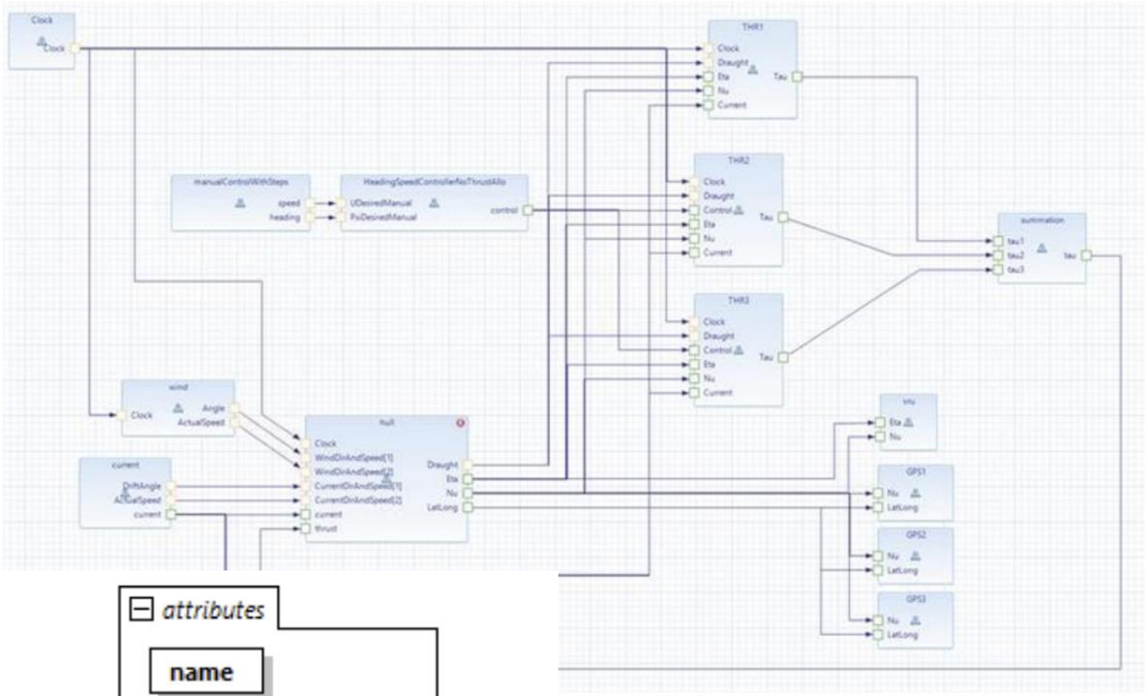


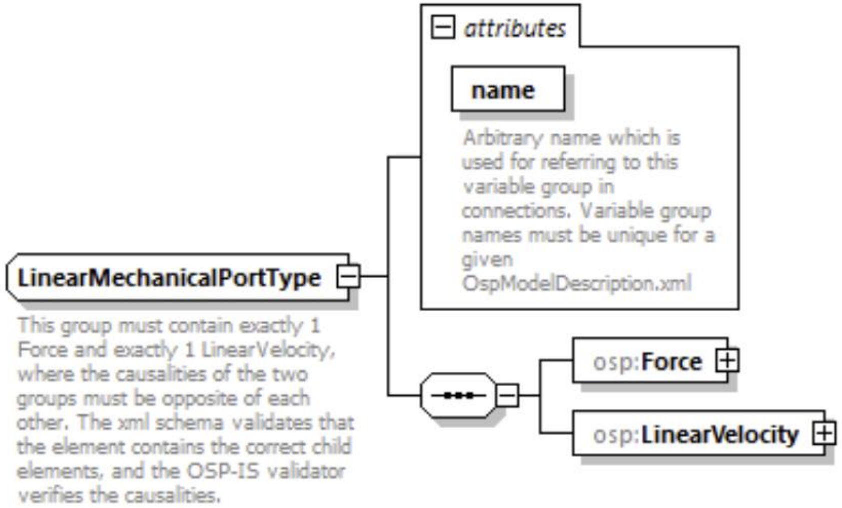
WP4 More accurate and reliable co-simulations

Simplify couplings: Marine vehicle simulations



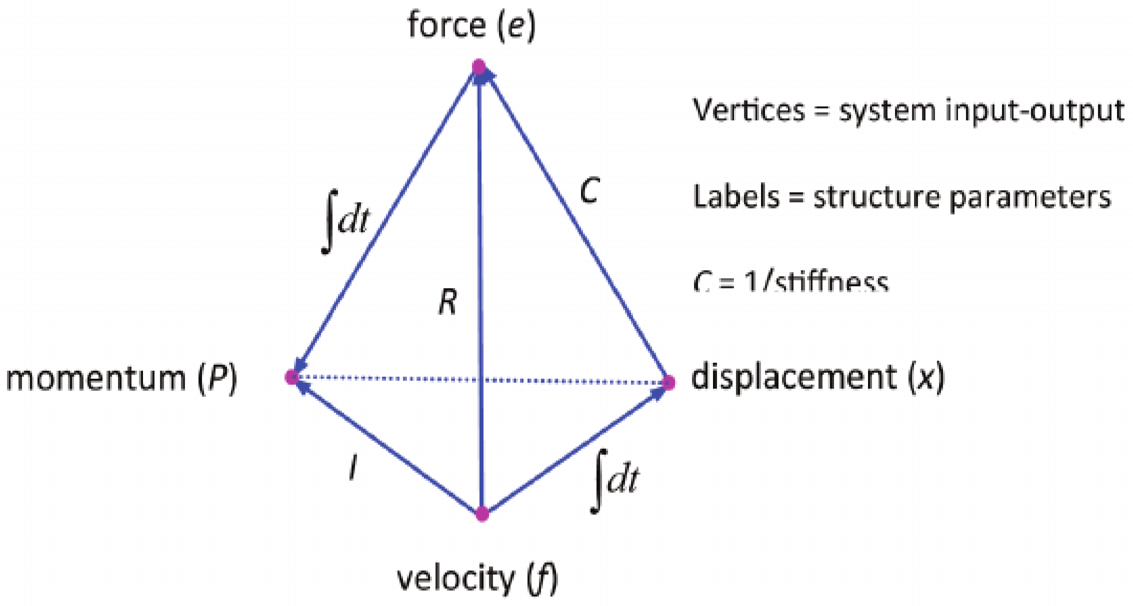
OSP-IS
FMI-LS





(Power) bond graphs

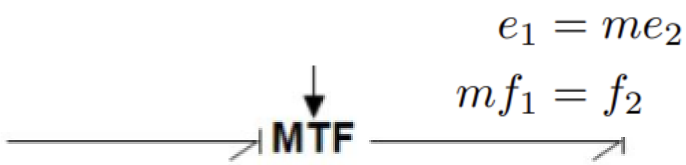
- Bidirectional connection for power exchange.
- Compact and tidy.
- Can model any physical system with the four quantities *e, f, p,* and *q.*
- Attractive for cross domain modelling.
- Maritime system models are challenging, but still benefit from this approach.

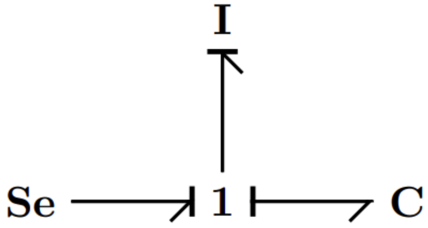


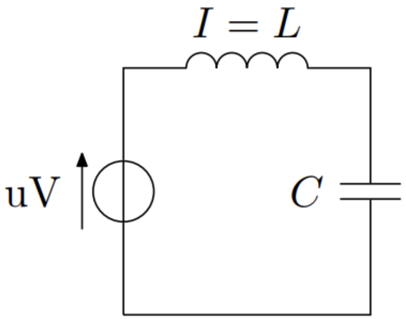
$$p(t) = \int^{t} e(t)dt = p_o + \int_{t_0}^{t} e(t)dt$$

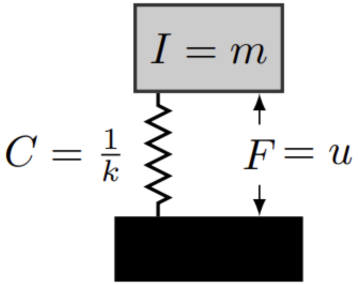
$$q(t) = \int^{t} f(t)dt = q_o + \int_{t_0}^{t} f(t)dt$$

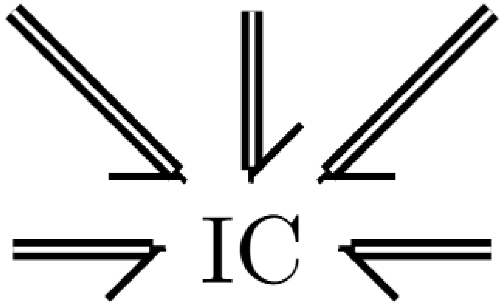
Coupling-focused modelling approach









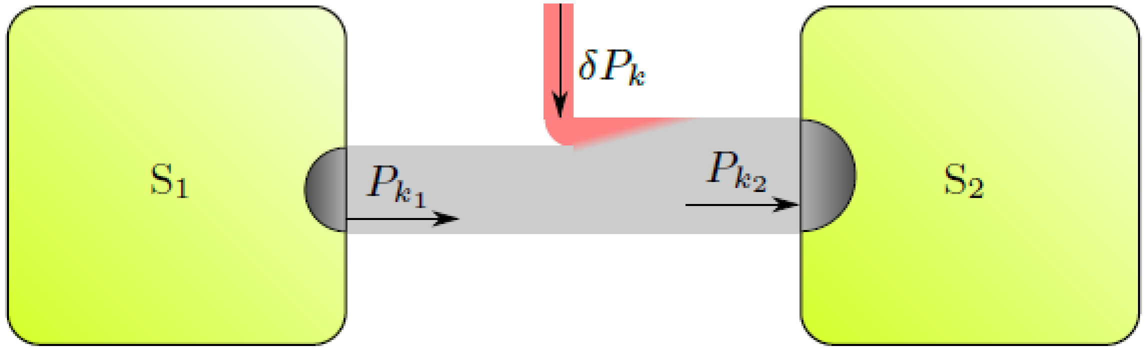


Coupled rigid body dynamics (vessel + crane)

- From Lagrange formulation, describe n-DOF rigid body mechanics as an IC field with $2n$ ports using generalized coordinates.
- Connect C and R ports to 1-junctions for external forces and moments.
- Describe inertial frame transformations with MTFs.
- Connect external systems through TFs / MTFs.

- Vessel + crane + load = 6+3+3 DOF.
- Not suitable with “brute force” IC field connecting all 12 DOF.
- Connecting IC fields directly leads to derivative causalities, which is unwanted.

Numerical errors & power bonds



In a co-simulation, $\mathrm{P}_{k_1} \neq P_{k_2}$!

Figure from [4]

Benefits of power bonds

- A better visual representation than free body or block diagrams.
- Enhances explainability of the modelling assumptions.
- Suitable for modular approaches.
- Domain agnostic.
- Less error prone modelling in many cases.
- Equally applicable for nonlinear systems.
- Attractive error estimation and step size control, such as exemplified by the *Energy-Conservation-based Co-Simulation method* (ECCO) [4] [5].
- Quantification of input uncertainty.
- Bond graph structure can be beneficial for certain fault detection methods such as analytical redundancy relations.

SeaCo Crane Use Case

Environmental influence: Fixation movement (through vessel). Load movement (wind).

Coordinate systems: Geographic – crane fixation – crane tip.

Tight couplings: Vessel – crane, slewing brake – power generation.

Verification and testing: Need to trust the simulation results if the crane model shall be used for optimizing crane choice, operations planning, training.

Scaling of cranes on a capacity range of factor >100.

Rather inexperienced FMU provider.

Q & A

www.dnv.com

References

[1] Dean C. Karnopp, Donald L. Margolis, Ronald C. Rosenberg. **System Dynamics: Modeling and Simulation of Mechatronic Systems, 5th edition.**

[2] Eilif Pedersen. **Bond Graph Modeling of Marine Vehicle Dynamics.**

[3] Børge Rokseth, Stian Skjong, and Eilif Pedersen. **Modeling of Generic Offshore Vessel in Crane Operations with Focus on Strong Rigid Body Connections.**

[4] Severin Sadjina, Stian Skjong, Eilif Pedersen, Lars T. Kyllingstad. **Energy Conservation and Power Bonds in Co-Simulation: Non-Iterative Adaptive Step Size Control and Error Estimation.**

[5] Severin Sadjina, Eilif Pedersen. **Energy Conservation and Coupling Error Reduction in Non-Iterative Co-simulations.**

[6] Dirk Zimmer. **A Modelica Library for MultiBond Graphs and its Application in 3D-Mechanics.**