Modelli di ordine ridotto e Intelligenza Artificiale per abilitare Digital Twin

SISSA mathLab

FAST COMPUTING

DUALISTIC

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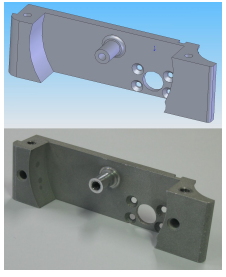
23/05/2025

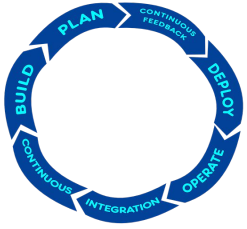
Digital Twin

Una lunga storia

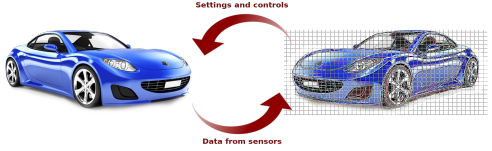
Prima simulazioni.



Primi strumenti di modellazione.



Le simulazioni diventano un tool consolidato in industria

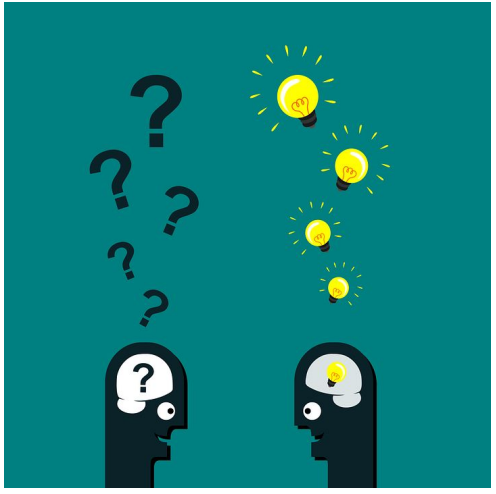


Dati e modelli per abilitare i Digital Twin

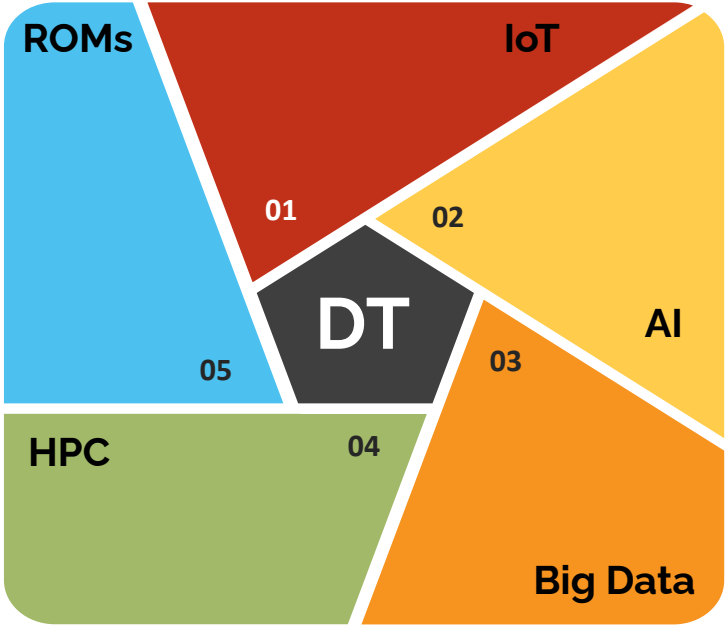
~1985 **~2000** **~2015**

A cosa serve un Digital Twin?

- *Progettazione e ottimizzazione (anche simulazione)*
- *Costi e tempi ridotti (anche simulazione)*
- Controllo del prodotto e del processo
- Manutenzione predittiva
- Supporto operativo
- **… Qualità migliore!**



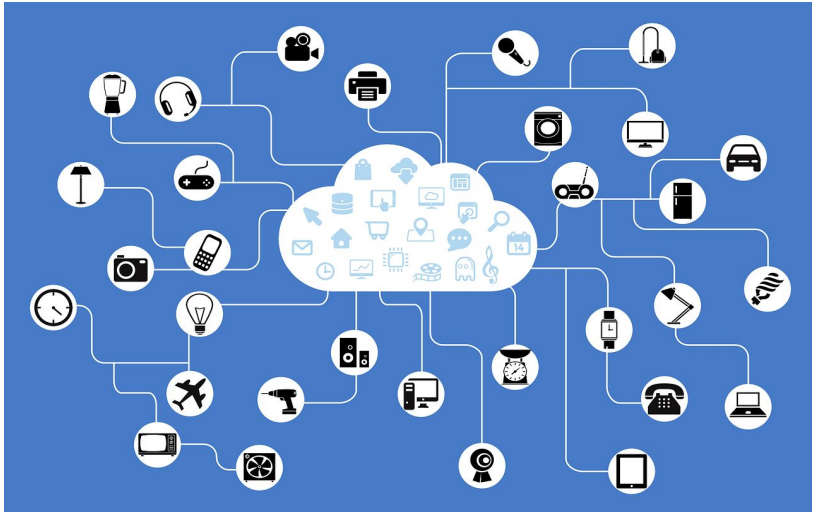
Digital Twin



Digital Twin

IoT

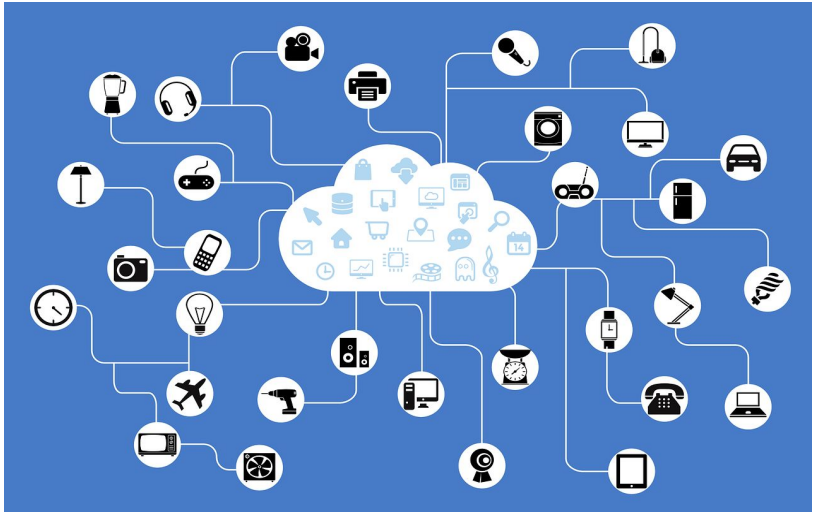
01



The Digital Twin

IoT

01



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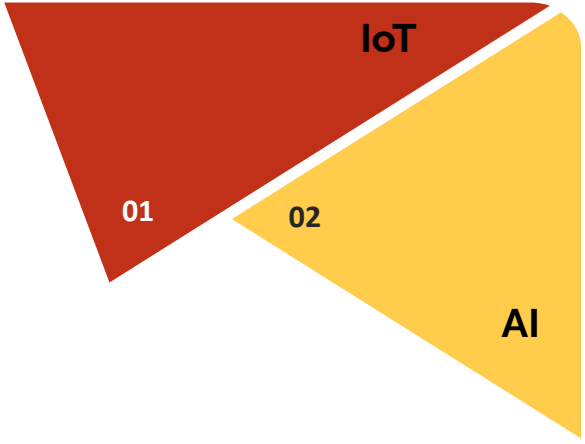

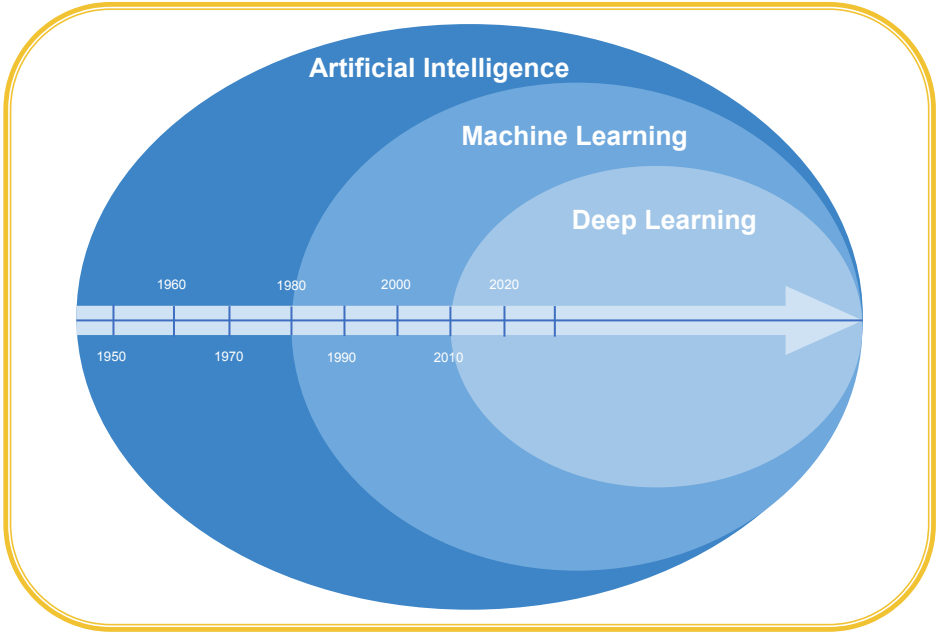

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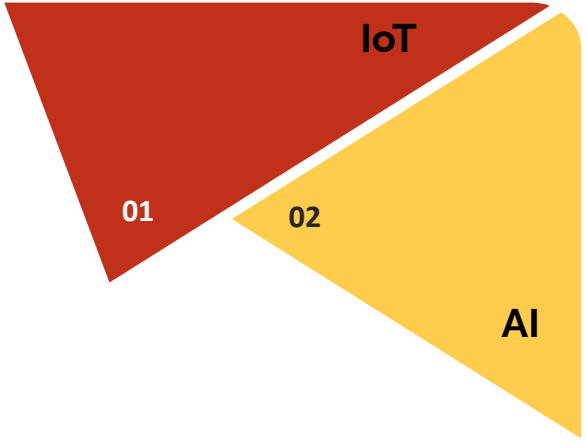
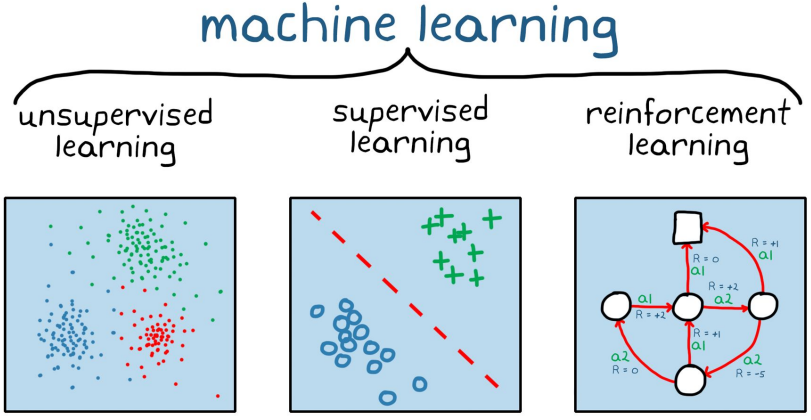


Il **Machine Learning** è un tema enorme e in costante crescita.
"[...] *Algoritmi statistici che possono apprendere dai dati e generalizzare a dati invisibili.*" da Wikipedia



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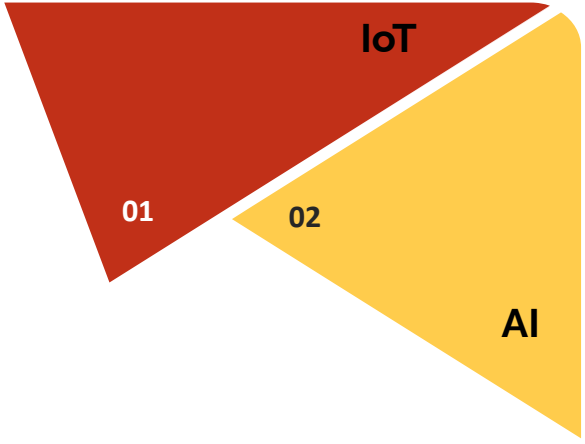


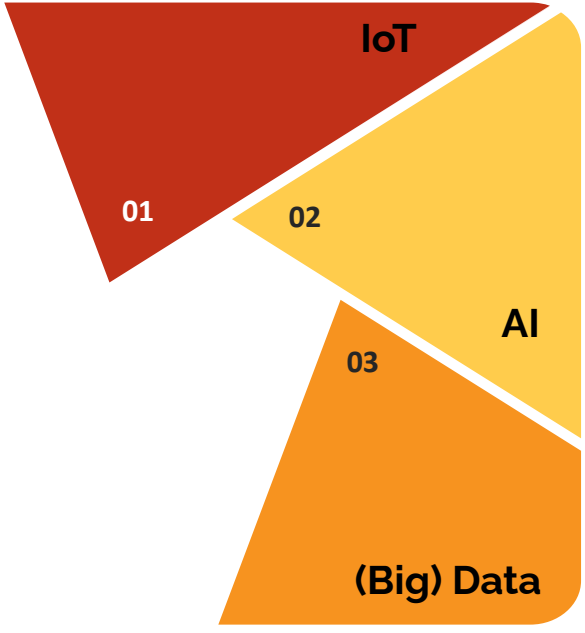
Le **reti neurali** sono un sottoinsieme dei metodi ML estremamente diffusi data la loro capacità di approssimare qualsiasi funzione.

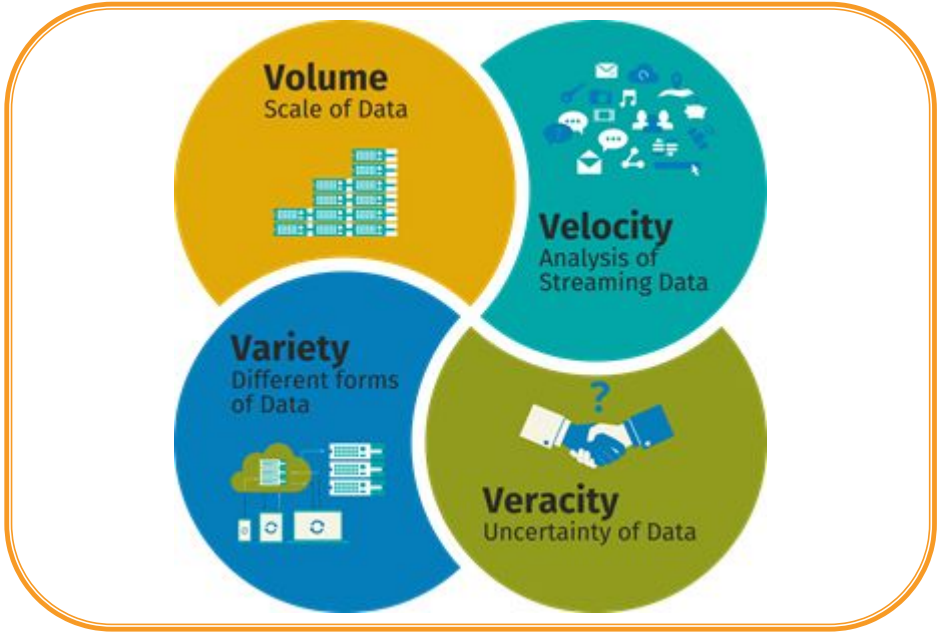
- mapping (non lineare) tra input e output
- regressione/interpolazione avanzata

Neural Net → Cat

$\mathbf{x}$ → Neural Net → $f(\mathbf{x})$

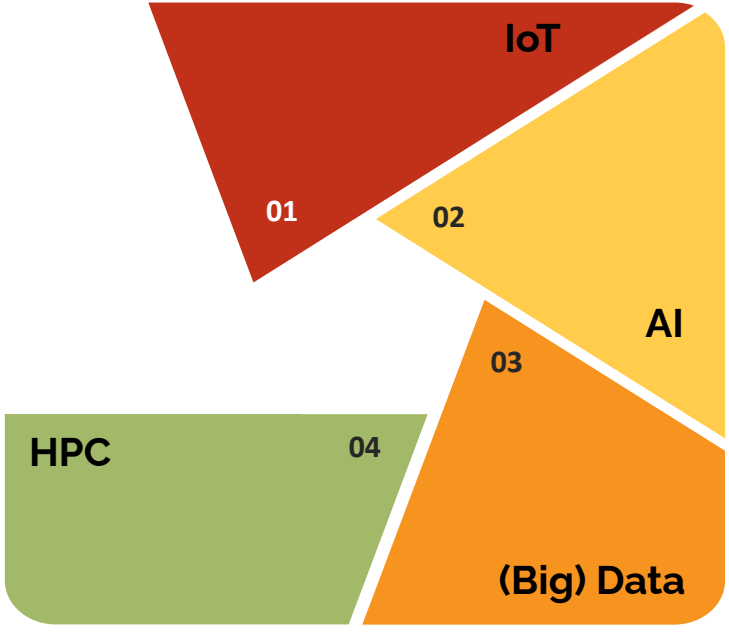
Digital Twin

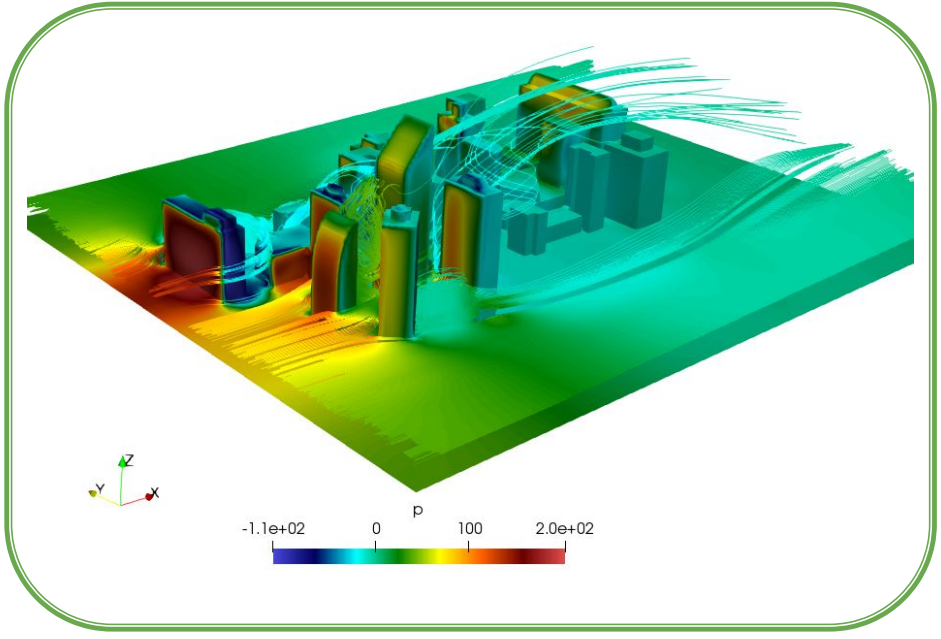




Source: www.hitachi.co.in

Digital Twin





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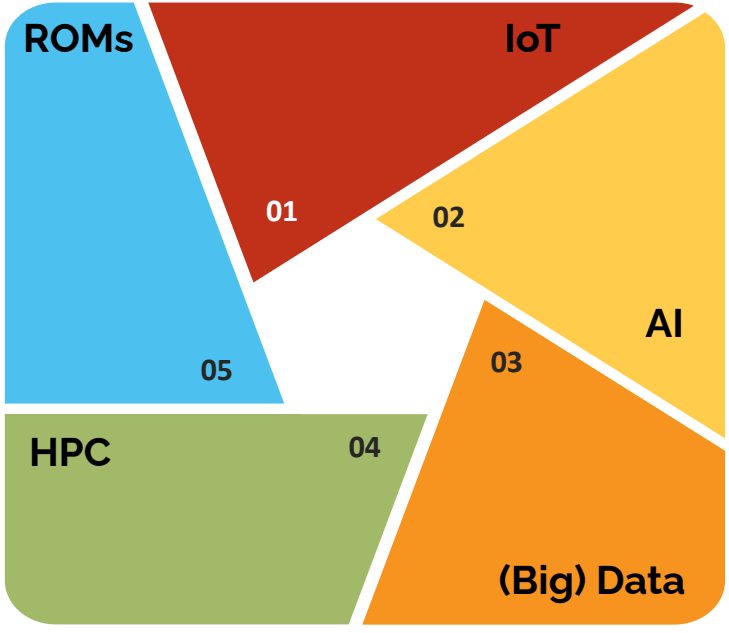
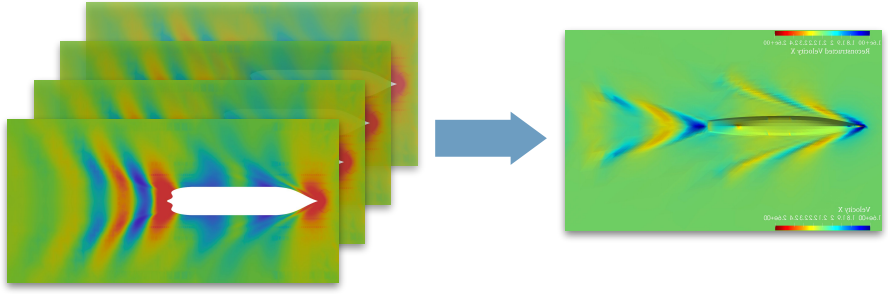


SOLUTIONS DATABASE
High computational cost (days)

ONLINE SOLUTION
Small computational cost (seconds)



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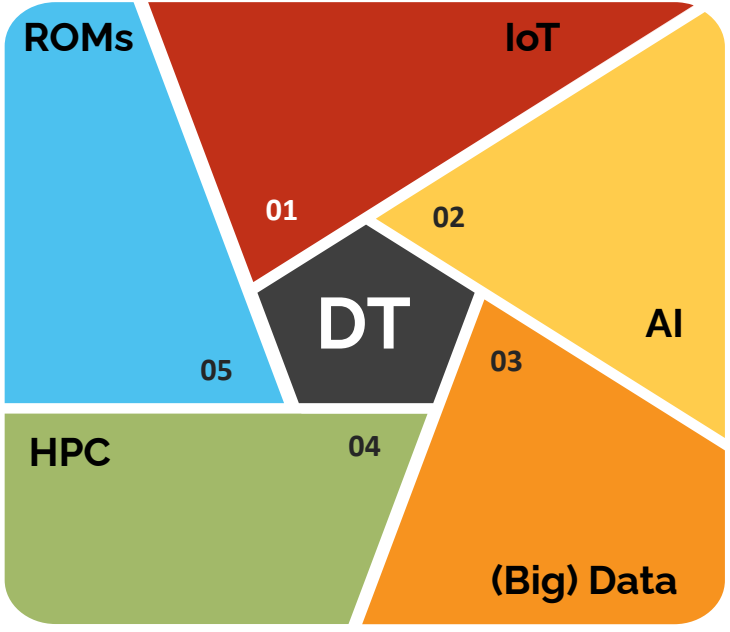
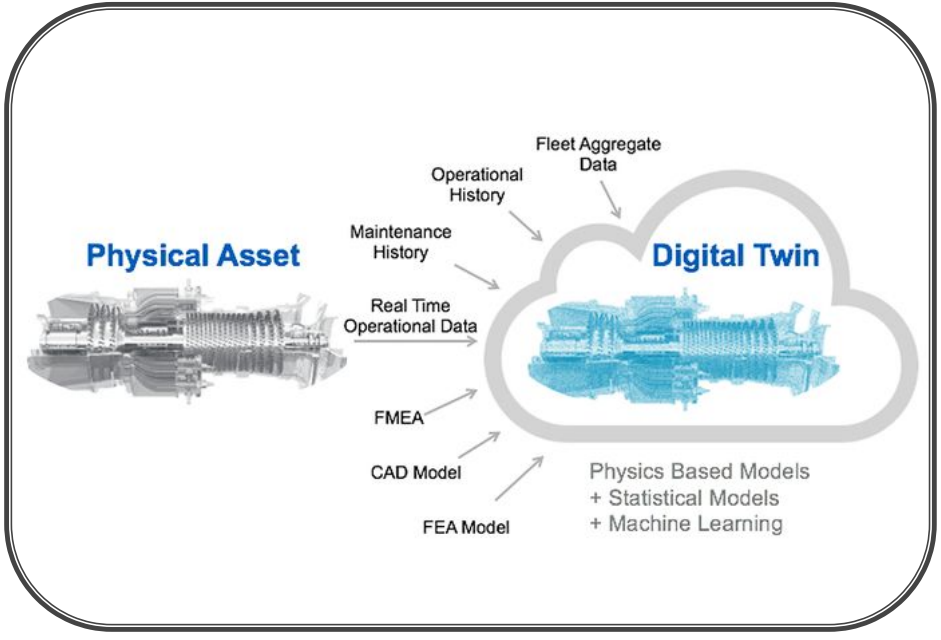


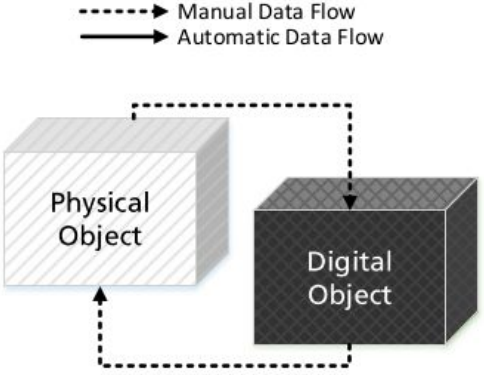


Source: www.entsoe.eu

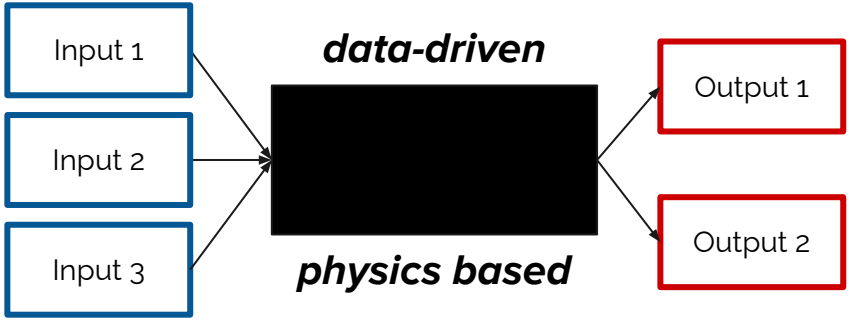
Un paradigma integrato

- Idea semplice, realizzazione difficile
- Integrato ma modulare
- Monitoraggio continuo

Perché abbiamo bisogno di Digital Twins?



Modello digitale



"Digital Twin in manufacturing: A categorical literature review and classification", Kritzinger, Karner, Traar, Henjes & Sihn, 2019.

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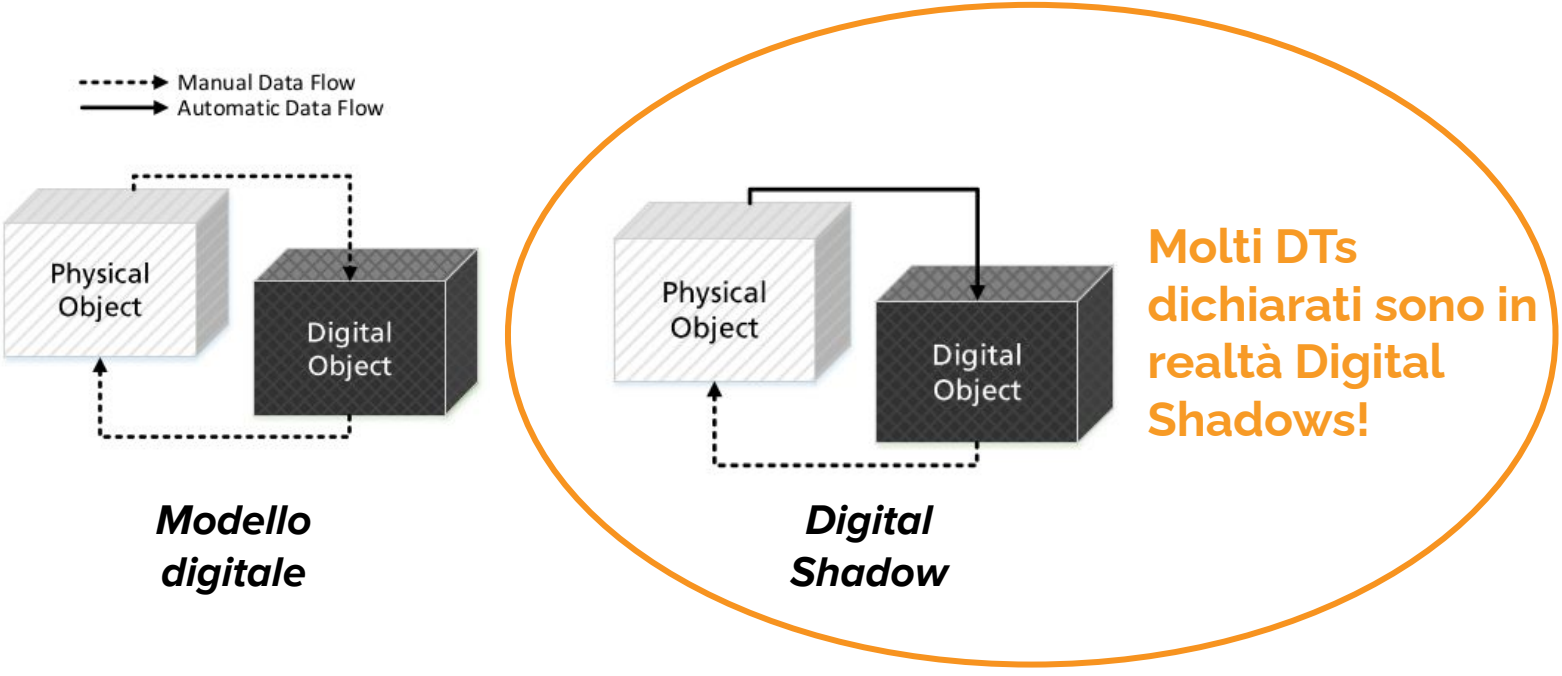

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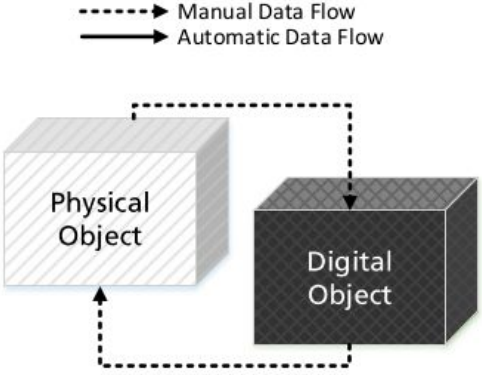

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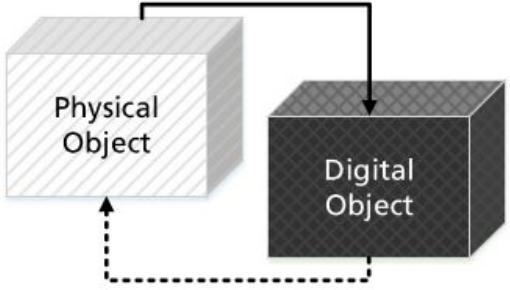
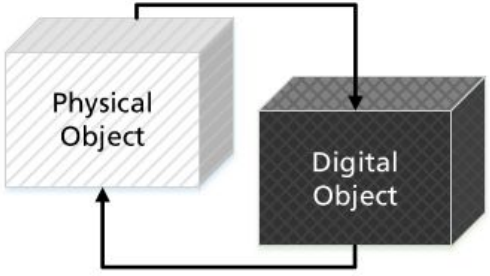


Digital Shadow



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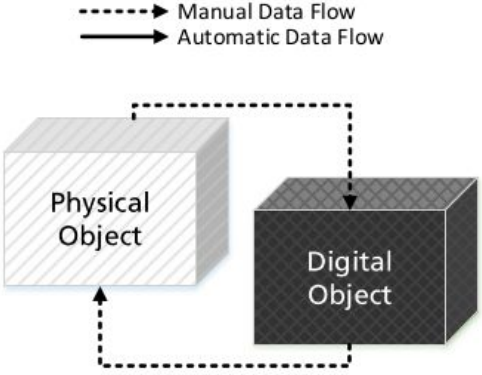
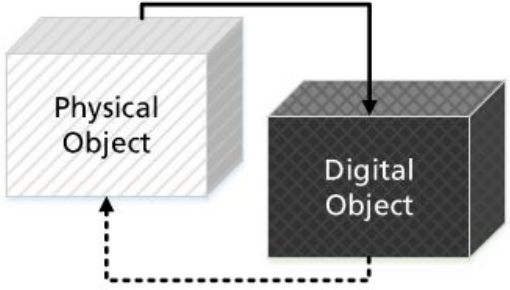
Perché abbiamo bisogno di Digital Twins?

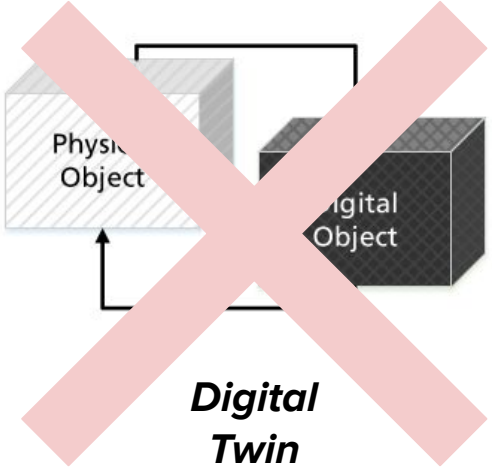
COSTI COMPUTAZIONALI



Modello digitale



Digital Shadow



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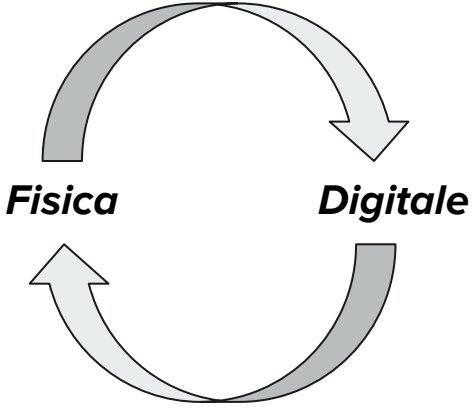
Cosa ci serve per creare il gemello digitale?



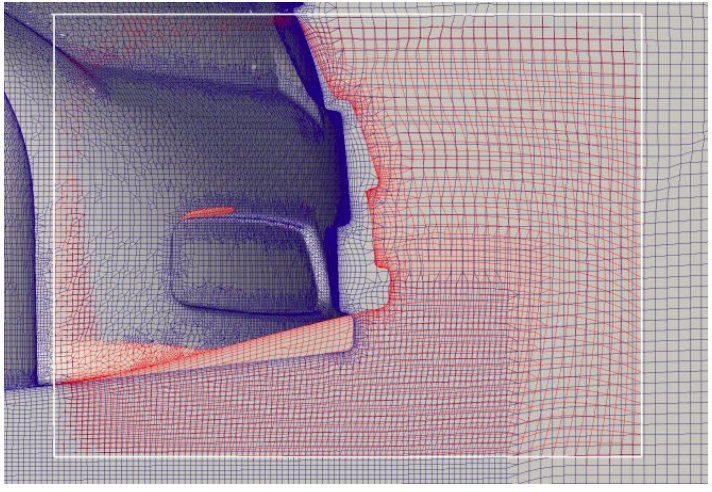
CALCOLO REAL-TIME

Reduced Order Modeling and Machine Learning

Simulazioni in poche parole

*Per **simulazioni** si intende la risoluzione di equazioni che descrivono i fenomeni fisici di interesse.*

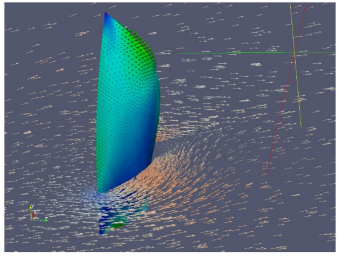
- Tipicamente equazioni differenziali (ODE, PDE)
- *Soluzione numerica*: il problema si divide in tanti problemi più semplici e questi vengono risolti (elementi finiti, volume finito,…)
- Meglio della validazione sperimentale, ma ancora lunga da calcolare

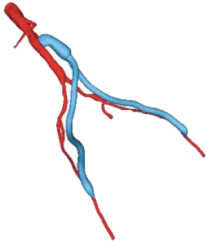


Non solo per i Digital Twin

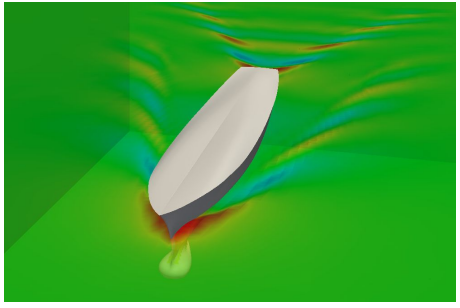
Negli ultimi anni c'è stata una crescente domanda di strumenti computazionali efficienti per

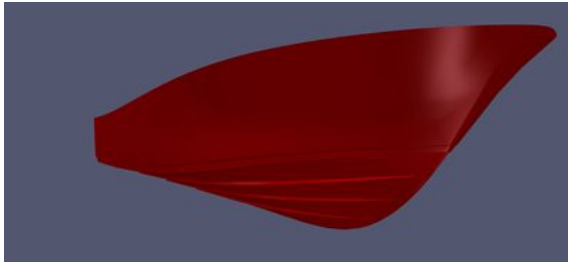
- **many query** e calcoli in **tempo reale**
- **formulazioni parametriche**
- simulazioni di **sistemi complessi** con scenari incerti

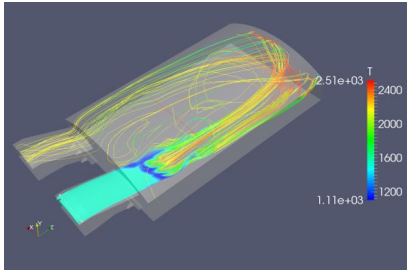


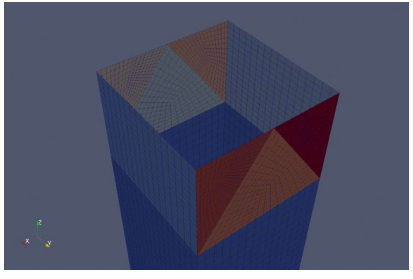


Applicazioni









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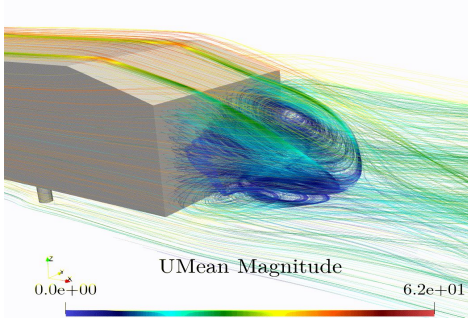

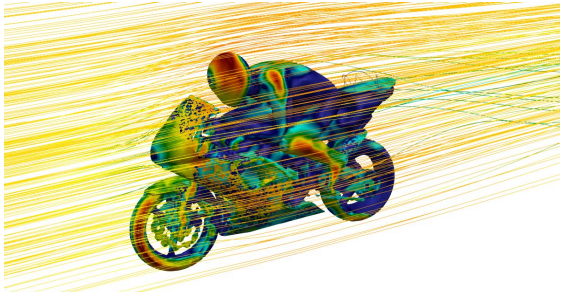

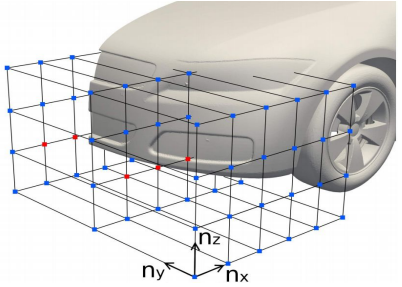

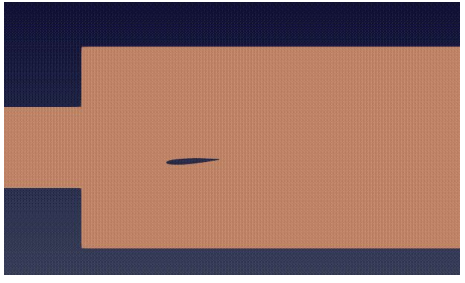

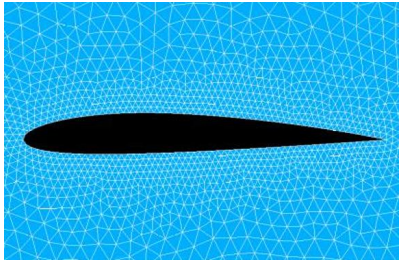

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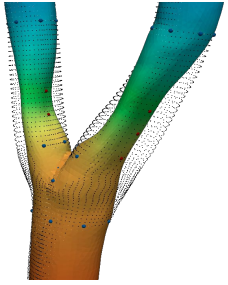
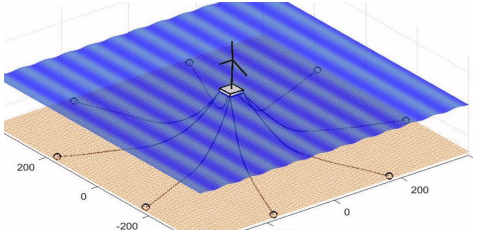
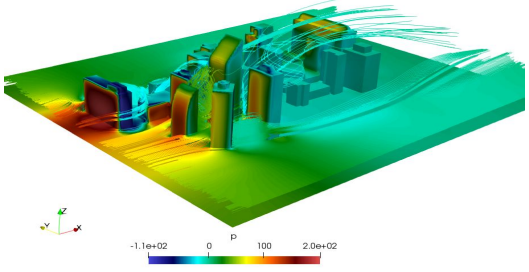


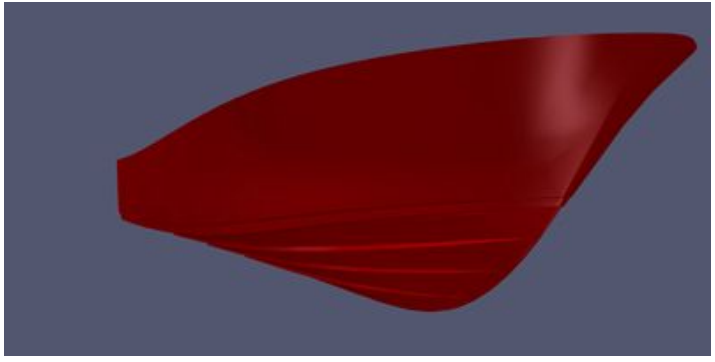


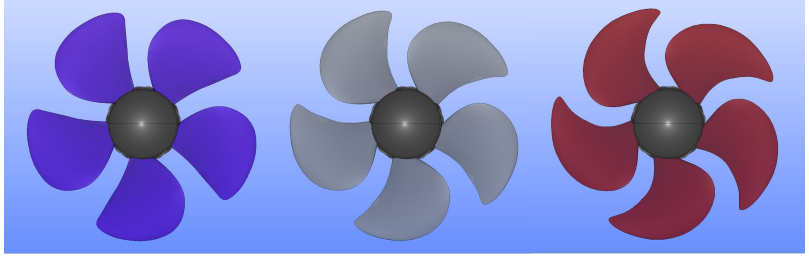


Paradigma intermedio: problemi parametrici

Problemi parametrici

- Non solo equazioni, ma equazioni parametriche
- Soluzioni necessarie per diversi parametri, molte risoluzioni!





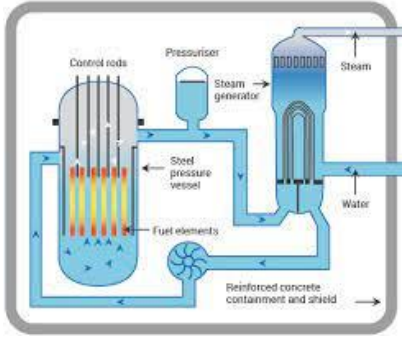
I parametri possono essere:

- **Parametri fisici** (ad esempio velocità, viscosità, ecc.)
- **Parametri geometrici**

Problemi parametrici: applicazioni

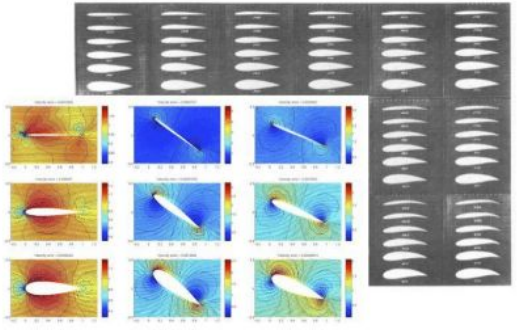
Optimal control

Qual è la migliore configurazione che devo imporre al sistema?



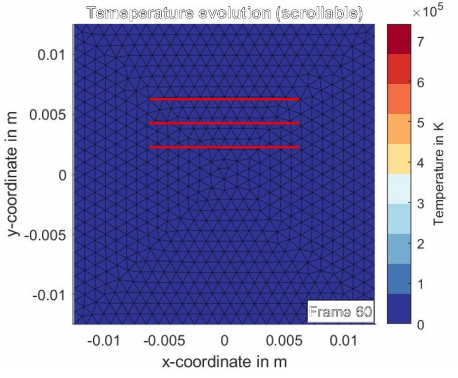
Shape design

Qual è la miglior forma del mio prodotto?



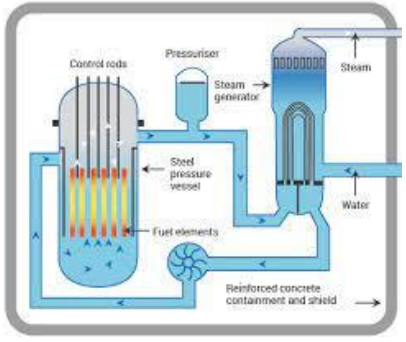
Inverse problem

Quali sono i parametri del mio sistema?



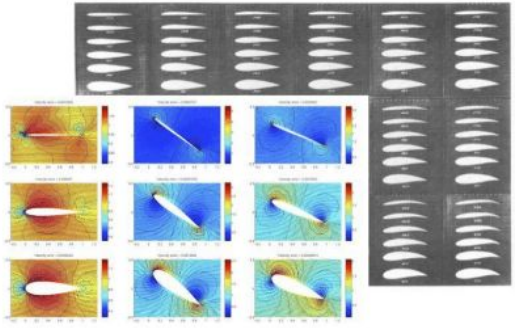
Parametric problems: applications

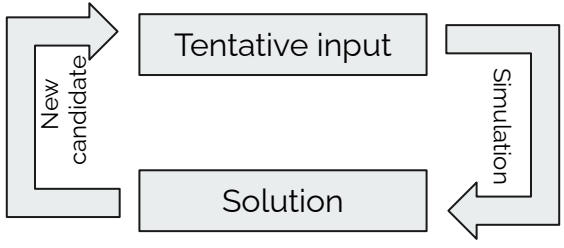
Optimal control



Ripetitive
Costose
Simulazioni

Shape design





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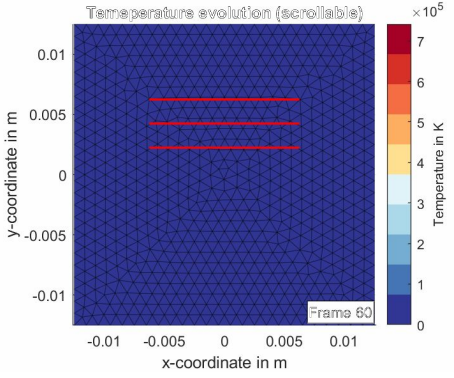


Procedure molto lunghe!

HPC è sufficiente?

I **supercomputer** vengono utilizzati per calcoli intensivi in diversi campi.

Negli ultimi anni la diffusione delle strutture HPC nel mondo industriale è stata favorita dai costi relativamente contenuti.

I computer HPC consentono simulazioni complesse, ma gli obiettivi industriali spesso richiedono molti calcoli ripetitivi.

Modelli surrogati: motivazioni

Problemi compless

Shape optimization, inverse problem, …

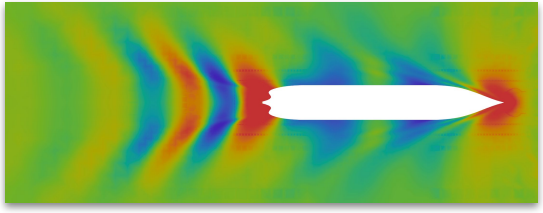
Tempo limitato

Potenza limitata

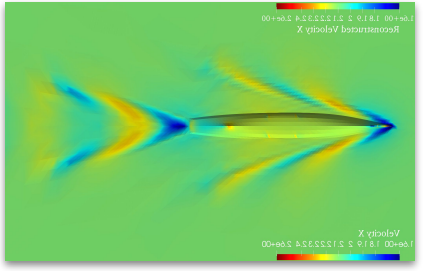
Un approccio sostenibile

Semplificazione del modello, piuttosto che **hardware più potente**

ORIGINAL MODEL



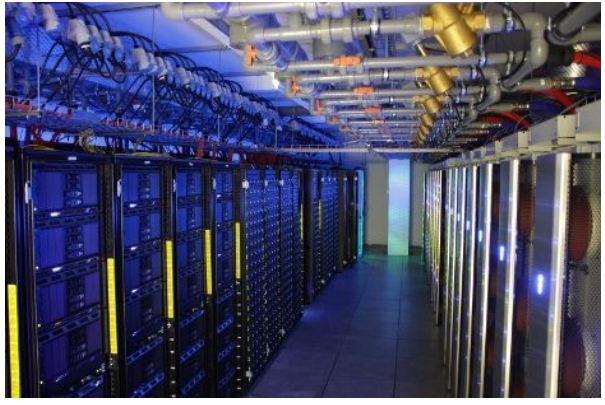
REDUCED MODEL



Le fasi computazionali

- **Offline stage**: calcolo di soluzioni ad alta fedeltà per la popolazione di un database - costo elevato
- **Online stage**: calcolo di un problema di ordine ridotto: su piccola scala, a basso costo, in tempo reale

Offline



Online

Non è solo questione di CPU time

Offline (calcolo singolo)

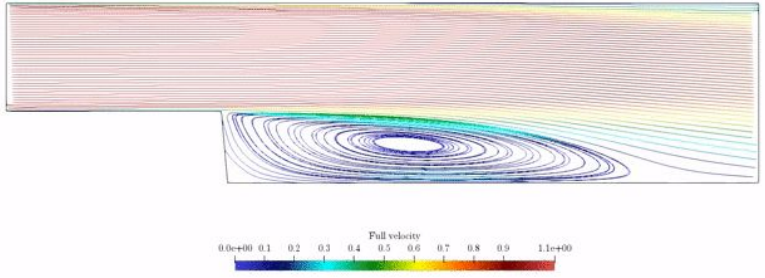
~1MW

Online (calcoli ripetitivi)

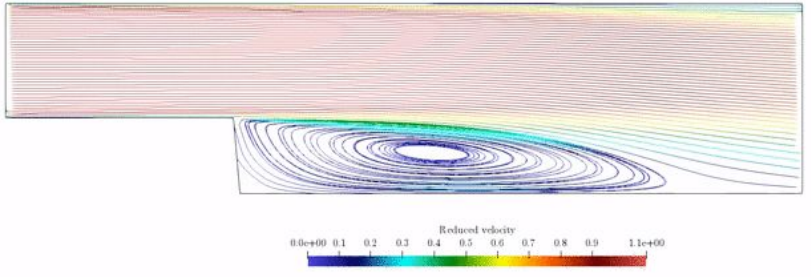
~100W

Ma quanto è accurata la soluzione?

Full order solutions

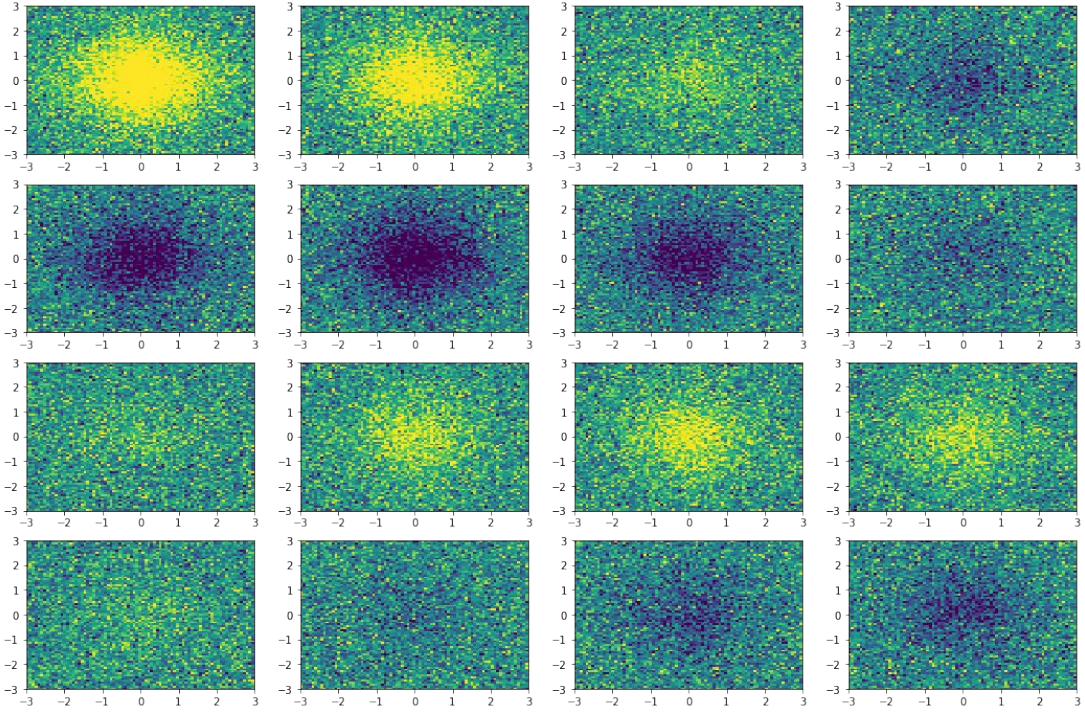


Reduced order solutions

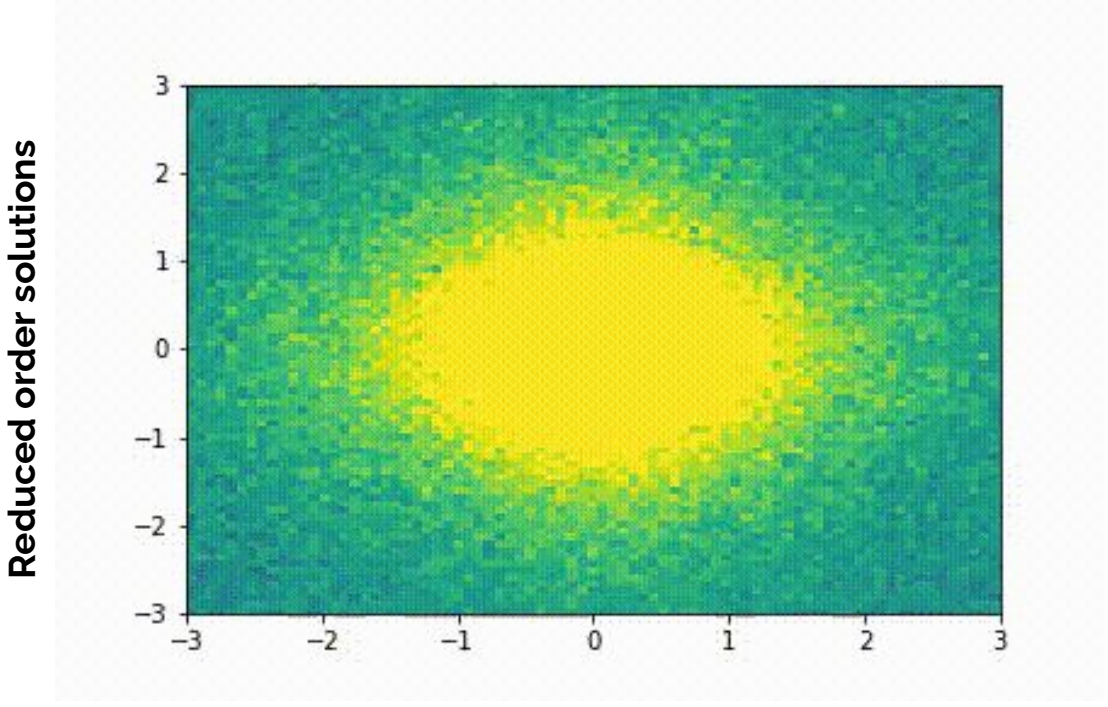


Ma quanto è accurata la soluzione?

Full order solutions



Ma quanto è accurata la soluzione?

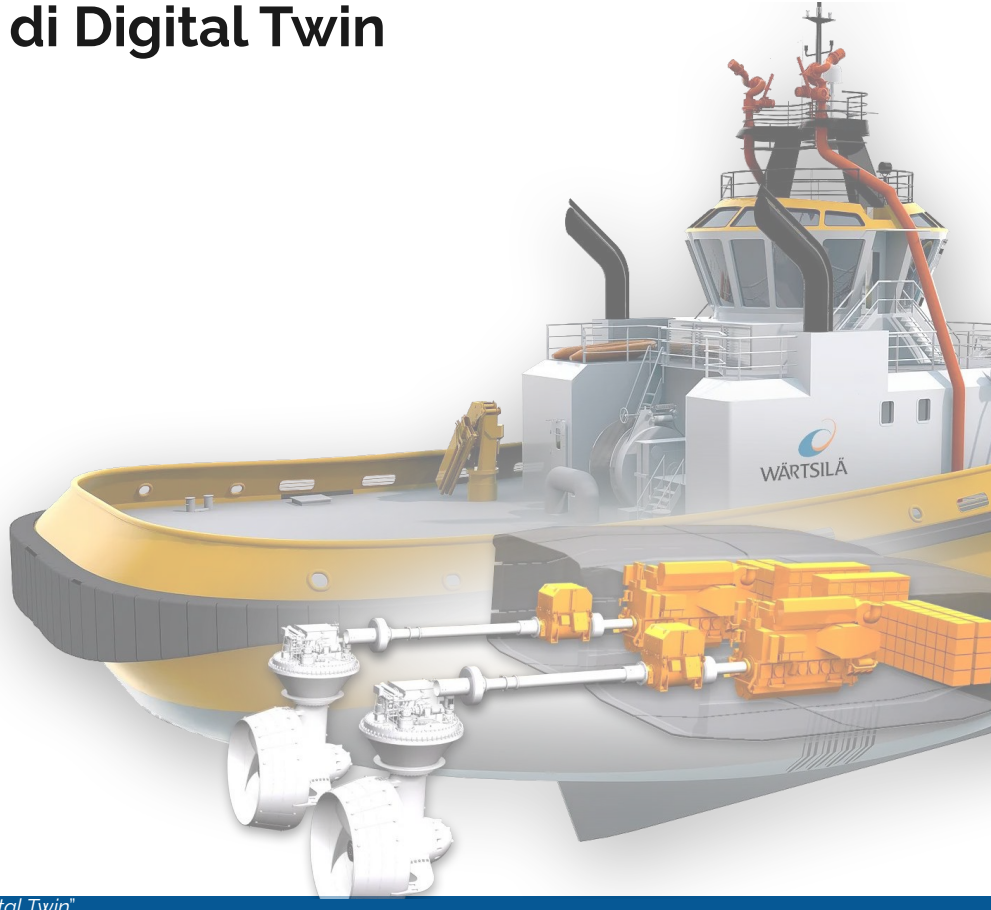


Un esempio di Digital Twin

SHEMS

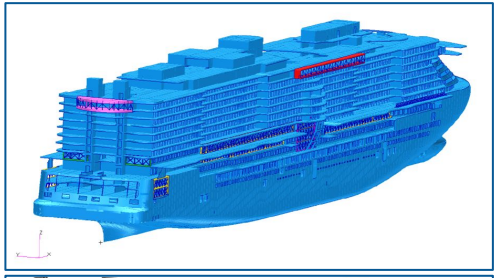
Ottimizzazione dell'efficienza del sistema di gestione energetica di Wärtsilä per motori ibridi:

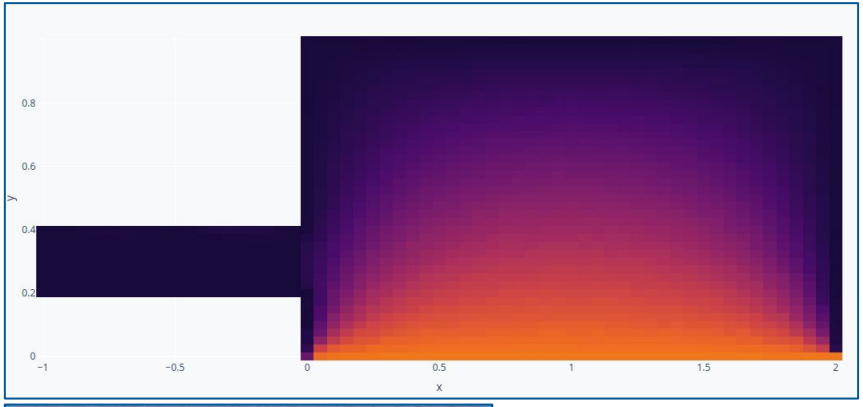
- Dati acquisiti dai sensori
- Rete neurale per la previsione della domanda energetica
- Algoritmo di ottimizzazione delle emissioni per migliori parametri operativi

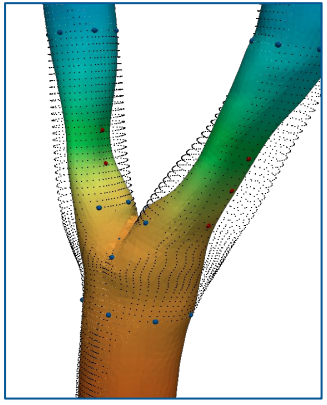


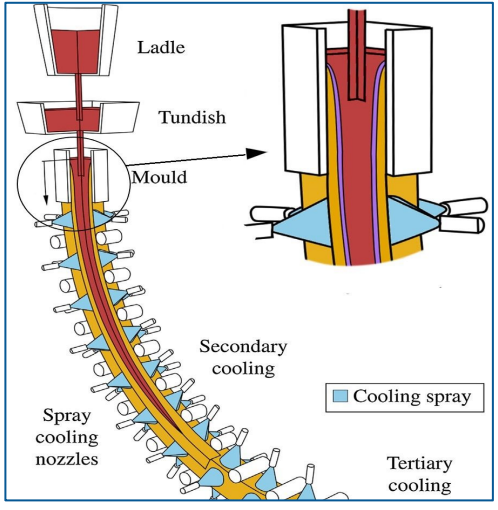
Un esempio di Digital Twin

Vuoi saperne di più?









Approfondiremo le tematiche sul Digital Twin e Simulazione nei prossimi corsi SMACT

STAY TUNED!

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