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The DLR strategy for MDO: Computationally and collaboration intensive MDO

...or, the **cybermatrix**

Caslav Ilic and the VicToria team

DLR

Motivation: Realistic multi-fidelity many-discipline MDO

- Experience with multi-fidelity many-discipline **MDO** in the Digital-X project
  - Reductions in consistency and design space to have feasible run times
  - Long development and integration times to a functioning process
  - Lack of performance and robustness in across-network execution
- Leaps in availability and expected use of **HPC** for design
  - DLR Strategy 2030, guiding concept 6 *"Virtual Product"*
  - NASA CFD Vision 2030, grand challenge 3 *"MDAO of a highly-flexible advanced aircraft configuration"*
- Cooperation between increasing number of diverse **actors**
  - Technical/organizational differences between disciplinary design teams
  - Disciplinary-tuned design methods, tools, and process implementations

- Another approach needed to reach the goals of the **VicToria** project

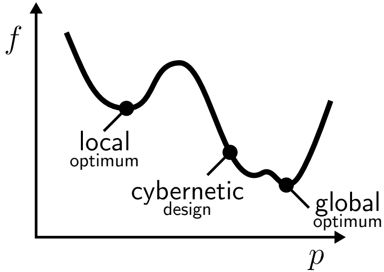
Representation: Universal design equation

- An **equation** that describes **any** design process?

$$\frac{d\widehat{f(w,p)}}{dp} - \lambda \frac{d\widehat{c(w,p)}}{dp} = 0, \quad c(w,p) = 0, \quad r(w,p) = 0$$

f – objective $\quad$ p – design parameters $\quad$ r – consistencies
c – constraints $\quad$ λ – constraint scales $\quad$ w – states

- **Implict approximate** KKT system of complex human-machine interaction
  - "Human in the equation", **cybernetic** Jacobians



Cybernetics:
a transdisciplinary approach to modeling, analysis, and control in complex systems

Representation: Cybermatrix

- Expand the design equation for multiple disciplines and a global objective

$$i = 1 \ldots n \text{ disciplines; } \min F(f_1, f_2, \ldots, f_n);\ f_i,\ c_i,\ p_i,\ \lambda_i,\ r_i,\ w_i$$

$$\widehat{\frac{\partial F}{\partial f_1}}\widehat{\frac{df_1}{dp_1}} + \widehat{\frac{\partial F}{\partial f_2}}\widehat{\frac{df_2}{dp_1}} + \ldots + \widehat{\frac{\partial F}{\partial f_n}}\widehat{\frac{df_n}{dp_1}} - \left\{\lambda_1 \widehat{\frac{dc_1}{dp_1}} + \lambda_2 \widehat{\frac{dc_2}{dp_1}} + \ldots + \lambda_n \widehat{\frac{dc_n}{dp_1}}\right\} = 0$$

$$r_1,\ c_1 = 0$$

$$\widehat{\frac{\partial F}{\partial f_1}}\widehat{\frac{df_1}{dp_2}} + \widehat{\frac{\partial F}{\partial f_2}}\widehat{\frac{df_2}{dp_2}} + \ldots + \widehat{\frac{\partial F}{\partial f_n}}\widehat{\frac{df_n}{dp_2}} - \left\{\lambda_1 \widehat{\frac{dc_1}{dp_2}} + \lambda_2 \widehat{\frac{dc_2}{dp_2}} + \ldots + \lambda_n \widehat{\frac{dc_n}{dp_2}}\right\} = 0$$

$$r_2,\ c_2 = 0$$

disciplinary design

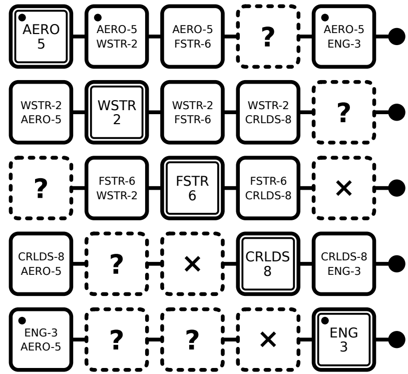
design top dependency

design interdependency

$$\vdots$$

$$\widehat{\frac{\partial F}{\partial f_1}}\widehat{\frac{df_1}{dp_n}} + \widehat{\frac{\partial F}{\partial f_2}}\widehat{\frac{df_2}{dp_n}} + \ldots + \widehat{\frac{\partial F}{\partial f_n}}\widehat{\frac{df_n}{dp_n}} - \left\{\lambda_1 \widehat{\frac{dc_1}{dp_n}} + \lambda_2 \widehat{\frac{dc_2}{dp_n}} + \ldots + \lambda_n \widehat{\frac{dc_n}{dp_n}}\right\} = 0$$

$$r_n,\ c_n = 0$$

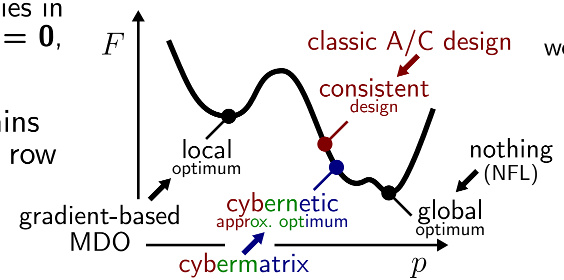


cybermatrix
working representation

N2 chart variant

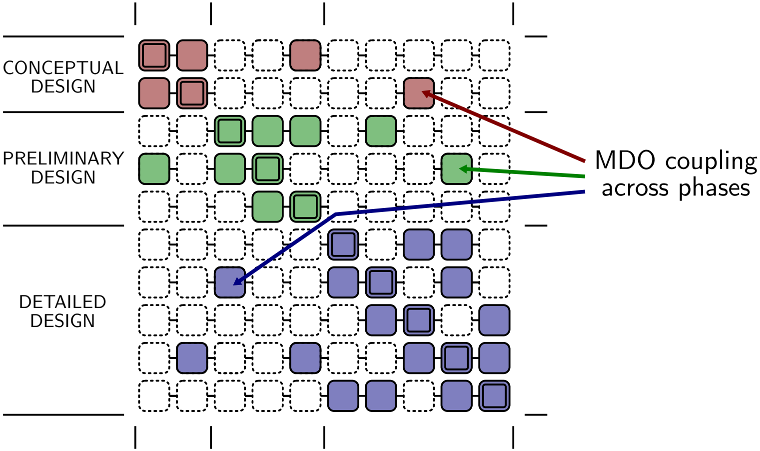
Top-/interdependencies in **classic A/C design = 0**, **MDO ≠ 0**

Every **actor** maintains full **control** of own row



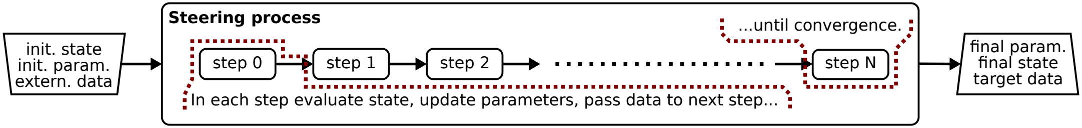
Representation: Cybermatrix reconfigurations

- Reconfiguration types: extension, decomposition, continuation
- Applying **extension** to design phases:



Realization: Disciplinary design processes

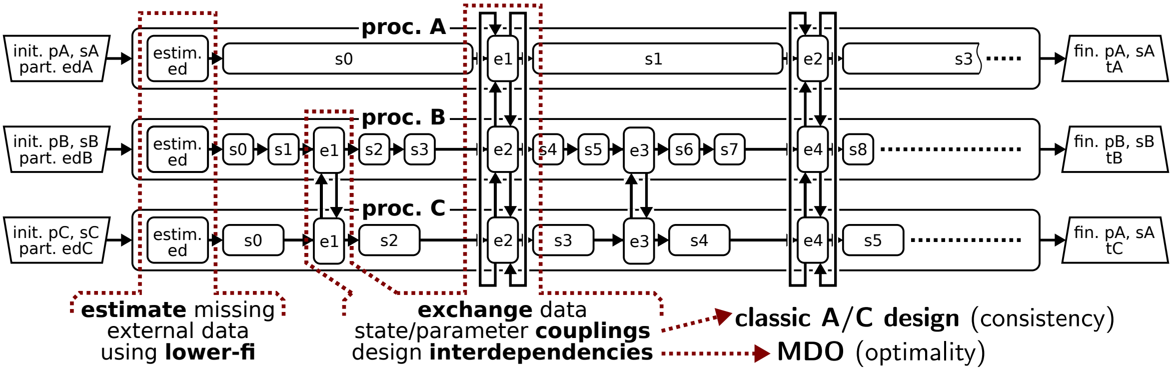
- **Cybermatrix row:** a disciplinary **iterative** design process



- Disciplinary process can be implemented in any language/framework
  - Input: initial state and parameters, external data (from other disciplines)
  - Output: final state and parameters, target data (to other disciplines)
  - Execution: top steering process visible as an OS process

Realization: Interleaved design processes

- **Cybermatrix:** design processes running **interleaved**, periodic data exchange



- **Data exchange:** exclusively file I/O, over **file system** in general sense

disk FS, mem. FS, parallel-disk FS, parallel-mem. FS, area network FS...
(workst.) (workst.) (cluster) (cluster) (multi-cluster/-workst.)

"Central consistent model"? None

"Central exchange database"? None

Realization: Parallel distributed assembly

- **Input collectors:** scripts for collecting **top/off-diagonal** data
  - Each actor provides one collector per other discipline it depends on
  - Collectors can be implemented in any language/framework
  - Actors can define data exchange directly among themselves
  - Cybermatrix representation extracted from comments in collectors

- **Automatic assembly** of a working MDO process
  - MDO process definition is a directory of input collector scripts
  - Input collectors are associated to disciplinary processes
  - Actors can test and debug own input collectors in parallel
  - Maintenance by standard software engineering practices

"Workflow integrator"?
None

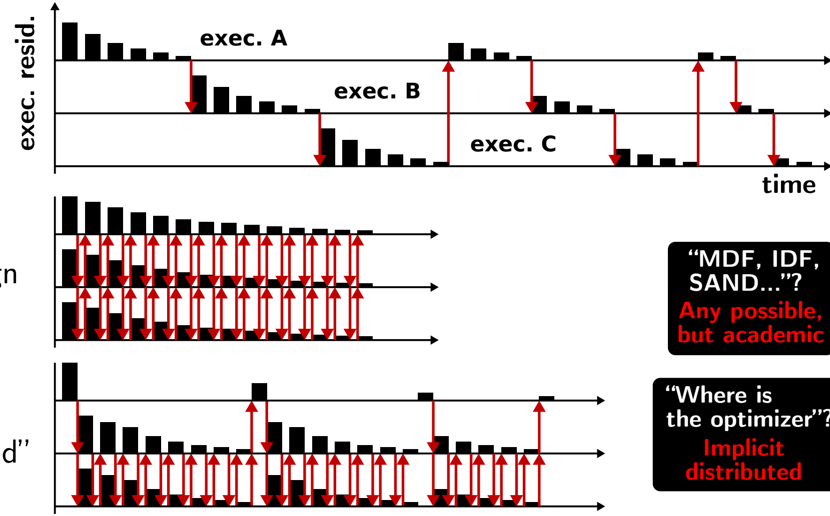
Realization: MDO formulations

- **Semi-automatic** using actor **hints**, or runtime **adaptive**
  - Periods of data exchange and damping per disciplinary process
  - Based on computing resources and properties of disciplinary processes

"Classic converger"
= sequential design
= Gauss-Seidel

"Outer one-shot"
= fully-interlvd. design
= parallel Jacobi

Real-world
= case-tailored "hybrid"



"MDF, IDF, SAND..."? Any possible, but academic

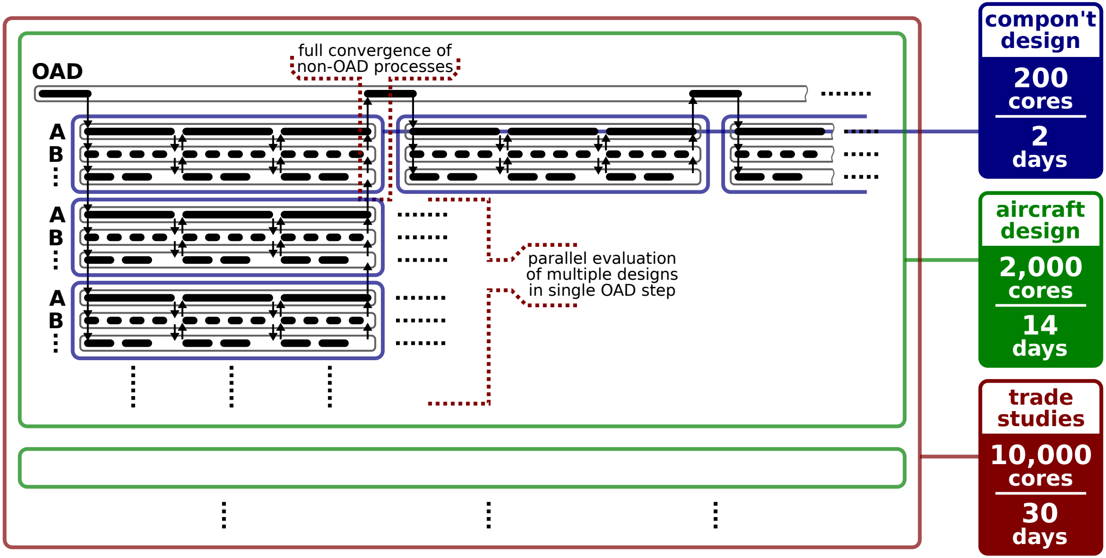
"Where is the optimizer"? Implicit distributed

Demonstration: DLR project VicToria

WP2: MDO
One of **three** process tracks

- **Resource**
  - Actors: 10 departments over 8 DLR institutes (20-30 people assigned)
  - Computing: 4,000-12,000 cores (DLR CASE-2 cluster + new)
- **Disciplinary design processes** (cybermarix rows)
  - Overall aircraft **(**label for next slide: **OAD)**
  - Multi-fidelity aircraft synthesis **(A)**
  - Wing/tail aerodynamics **(B)**
  - Wing/tail structure **(C)**
  - Fuselage structure **(D)**
  - Loads alleviation **(E)**
  - Flight stability **(F)**
  - Engine* **(G)** ← tentative
  - Flutter* **(H)** ← evaluation only, no design

Demonstration: VicToria MDO formulation



OAD: custom cybermatrix-tailored derivative-free optimization algorithm

Cybermatrix beyond state of the art (1)

* points beyond SotA for only some classes of approaches

- **Practicality**
  - Synthesis of experiences and interviews through 8 DLR institutes
  - Minimally sufficient way to reach the ambitious VicToria goals
  - Highly open to involving ad-hoc human inventivity
- **Fidelity**
  - Focus on top design fidelity of involved disciplines ("hi-fi")
  - Lower fidelities supported and expected in any practical process
- **Consistency**
  - Fully converged inter-disciplinary consistency*
  - Disciplines can formulate process-specific consistency needs*

HANDOUT

Cybermatrix beyond state of the art (2)

* points beyond SotA for only some classes of approaches

- **Optimality**
  - Gradient-free, gradient-based, and mixed processes supported
  - Solutions nearer to optimum than classic A/C design possible*
- **Paralellism**
  - Enormously parallel execution on HPC resources included ground-up
  - Distributed parallel process assembly and debugging among actors
- **Tolerance**
  - Graceful deterioration of optimality in face of missing capability
  - All actors continue to use their own development environments

New MDO integration framework for HPC:
DLR Institute of Software Methods for Product Virtualization
est. **2017 (**IT/math. branch**)**

Thank you for your attention!

Questions?

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Some research questions

MATH
Distributed reformulations of optimization algorithms

INFO
Effective execution of cyberm'x row processes on HPC resources

MATH, INFO
Assisted discovery and quantification of design interdepend's

ENGN, INFO
Collaborative assembly and comprehension of cybermatrix represent's

MATH
Parallel extensions to optimization algorithms

INFO
Site/hardware-specific filesystems for cybermatrix execution

MATH, INFO
Automatic and runtime-adaptive row interleaving

ENGN, INFO
Relaxing and blending different fidelity external data

MATH
Inexact evaluation reformulations of optimization algorithms

INFO
Reduction of limits to HPC use in multi-site distributed frameworks

MATH
HPC-capable model problem derivation from actual problem