Scientific Visualization for Decision Support

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“Tell me and I'll forget; show me and I may remember; involve me and I'll understand.”

Chinese proverb
Scientific Visualization for Decision Support: Industrial Vision

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Decision making loop in design

Evaluate requirements impact

requirements

Decision space

decision

Synthesis to support decision making

• Synthesis of important parameters
  - What are the limits and where are they.
  - Impact of component performances on global performances

• Propose trade-offs
  - Between requirements
  - On design parameters

• Manage risks
  - Quantitative evaluation

Systematic and automatic exploration

• Understand the design space
  - What are the important parameters?
  - How the requirements interact with each other?
  - Where are the most promising solutions?

• Generate models dedicated to decision making
  - Trade-offs
  - Evaluate risks

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Design loop

- Customer requirements
- Technologies
- Levels of fidelity
- Objectives
- Constraints
- Design variables
- Define Problem
- Define Design Space
- Models and Simulation
- Explore Design Space
- Evaluate solutions
- Select solution

Visualization

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Technical challenges:

- Management of a hierarchy of interoperable surrogate models
- Evaluate the robustness of results wrt risks and uncertainties
- Exploration techniques adapted to the different level of fidelity of the models
- Methodology to analyze the design process of complex systems
- Develop interactive visualization tools to support decision making

Inspiration:

Georgia Tech ASDL
Collaborative Visualization Environment
Goal: Interactive design reviews

"Performance" view

"Physical" view

"System" view

Interactive visualization of the impact of the design parameters on
- global performances
- physical solutions
- component behavior
Initial step

Prototype in Matlab

- Identify key functionalities
- Test / evaluate solutions

Mathematical tools
Ergonomy
Visualization techniques

To be consolidated in CSDL

"Static" Analysis

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From static to dynamic

- Use surrogate models

- Surrogate models:
  - Interactive "dynamic" analysis
  - Experimental design
  - Analysis of variance

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Scientific Visualization for Decision Support: Scientific Research Vision

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• Visualization: Wish List & Challenges
  Anastasia.Bezerianos@ecp.fr

• Online Analysis and Exploration Process
  Florian.De-Vuyst@ecp.fr

• Data Modeling and Semantics
  Rim.Djedidi@ecp.fr
• Visualization: Wish List & Challenges
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CSDL: Visualization Wish List

- Interactive Visualization
- Collaborative exploration
- Exploration History
- Interactive Visualizations (Surrogate Models)
- Interactive Visualizations (Surrogate Models)
  - Interactive result exploration in different views
CSDL: Visualization Challenges

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  - Interactive result exploration in different views
CSDL: Visualization Challenges

- Interactive Visualizations (Surrogate Models)
  - Interactive result exploration in different views
  - Interactive data re-sampling, define and present
CSDL: Visualization Challenges

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  - Interactive result exploration in different views
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CSDL: Visualization Challenges

- Collaborative exploration
CSDL: Visualization Challenges

- Collaborative exploration
  - What interaction mechanisms to provide
  - How to treat conflicting requests

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CSDL: Visualization Challenges

- Collaborative exploration
  - What interaction mechanisms to provide
  - How to treat conflicting requests

- Distributed settings, additional challenges:
  - How to handle multiple requests and delays
  - How to treat mixed infrastructure
CSDL: Visualization Challenges

- History
- Provenance and Storytelling, Latecomers
CSDL: Visualization Challenges

- History
- Provenance and Storytelling, Latecomers
  - How to go back to previous exploration steps?
  - How to visualize paths that lead to decision?
  - How to summarize current exploration state?
Overview

• Visualization: Wish List & Challenges
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• Online Analysis and Exploration Process
  Florian.De-Vuyst@ecp.fr

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Dealing with Highly-Dimensional FE Solutions

\[ \theta \in \mathbb{R}^p \rightarrow \text{FE computations} \rightarrow J(\theta) \]

\[ u^\theta(x) = u(x, \theta) \]

Discrete: \( U^\theta \in \mathbb{R}^d, \ J^\theta \in \mathbb{R}^q \)

Typically: \( 1 \leq p \leq 400, \ 1 \leq q \leq 50 \)
\( 10^5 \leq d \leq 10^8 \)
Usual standard approach (commercial software):

- **Design parameters** $\theta \in \mathbb{R}^p$
- **Response $J(\theta)$**

**Metamodelling**

**Response Surface Methodology RSM**

$$\tilde{J}(\theta) = \ldots$$

- Scatterplots
- Pareto
- Clustering
- Check into physical space

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Usual Process of Exploration and Analysis

Define parameter space

(Re)-define criteria, cost functions, constraints, …

DOE

RSM

Visualize, explore, analyze, decision process

Check, verify in physical 3D space

CPU TIME CONSUMING!

Big latency

while not satisfied 😞

→ Not suitable for online progressive visualization & analysis

DOE : Design Of Experiment
RSM : Response Surface Methodology

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A Suitable Progressive Online Visualization Process

Define parameter space

(Re)-define criteria, cost functions, constraints, …

Visualize, explore, analyze, decision process

Check/verify in physical 3D space

Done once for all!

Need storage data modeling (FE)

Adaptive non-blocking asynchronous metamodel refinement

while not satisfied 😊

Collaborative online visualization environment

DOE : Design Of Experiment
DB : DataBase
DWH : Data WareHouse
RSM : Response Surface Methodology

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Example of POD-Based FE Reduced-Order Model
(local POD-ISAT ROM - Dung Bui PhD thesis, ECP)

\[ \tilde{u}_{(\theta)}(x) = u^{lift}(\theta)(x) + (u^i - u^{lift}(\theta^i))(x) \]

\[ + \sum_{k=1}^{K} a_k(\theta) \Psi_{(\theta)}^k(x) \]

**Design space**
- Trust region
- DOE sampling points

**Local surrogate model at point \( \theta^i \)**

**Easy-to-compute lifting function (for BC)**

**Shift**

**Local POD modes**

**POD coefficients** (need a learning step)

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\[ R(\bar{u}^\theta) \leq \varepsilon_{\text{threshold}} \]

Database content:

- The "center" point \( \theta^i \)
- The FE solution \( \bar{u}^i = u(\theta^i) \)
- A local surrogate form \( \bar{u}(\cdot,\theta) \)
- Some POD coeffs \( a_k(\theta) \) computed by minimization of the residual
- A Trust region model \( \tilde{R}(\bar{u}^\theta) \) computed from a SRM of the residual
Integration into the Progressive Collaborative Online Visualization Environment

- Need to “explore” a new design area
- Is there any accurate surrogate?

**YES**
- Good! Keep going.
- Visualize …

**NO**
- Oops! Create new local surrogate
- Improves residuals and trust regions accuracy of existing local surrogate models (if necessary)
- Inform user and collaborators
- Alert! Ongoing modeling…

**MAIN TASK**

**PARALLEL THREAD**

**ONLINE**

**ENRICH**

**REFINE**

Timeline

On-the-fly!
• Visualization: Wish List & Challenges
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• Online Analysis and Exploration Process
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• Data Modeling and Semantics
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Data Modeling Requirements for online visualization process

**Experiment**
- Define parameter space
- (Re)-define criteria, cost functions, constraints, …
- Need storage data modeling (FE)
- Done once for all!

**Exploration & Learning & Decision support**
- Visualize, explore, analyze, decision process
- Check/verify in physical 3D space
- Adaptive non-blocking asynchronous metamodel refinement
- while not satisfied 😊

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**Definitions**
- DOE : Design Of Experiment
- DB : DataBase
- DWH : Data WareHouse
- RSM : Response Surface Methodology
Scientific Data Modeling

Experiment Level

- Raw Data Set
  - Design Parameters
  - FE solutions of DOE Sampling points

Exploration & Learning Level

- Criteria, Cost Functions, Constraints, …
- Surrogate models
  - Example POD Reduced-order model
    - POD Modes, POD coefficients, Trust Region
- Design preferences
- Multiple customizations
2 Systems to coexist!

1. Operational system for data storing
   ➔ Learning Database (DB)

2. Data restore & multidimensional analysis system
   ➔ Data Warehouse (DWH)
Preliminary Architecture

Experiment

Exploration & Learning & Decision support

CSDL environment for Smart Visualization

Process Layer

Interactive Analysis

Data Layer

Data Storing

Data Restore & Multidimensional Analysis

Data Capture & Update

ETL Process

Interoperability Layer

Independent Operational Systems

IS : Information System
ETL : Extracting, Transforming, Loading

Design Instance

Dimension 1
Dimension 2
Dimension 3
Dimension n

Analysis & Reporting Tools → Decisional System

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2 Systems to coexist!

1. Operational system for data storing
   ➔ Learning Database (DB)

2. Data restore & multidimensional analysis system
   ➔ Data Warehouse (DWH)
   • Combining several multidimensional models (data marts)
     – One multidimensional model for each analysis axis
   • Coherent set of dimensions and facts
     – Temporal, spatial or thematic dimensions
     – Facts modeling design instances (criteria & aggregated functions)
Common and shared vocabulary

- Structuring and Integrating data extracted from heterogeneous data sources
  ➔ Interoperability Layer
Preliminary Architecture

Experiment
Exploration & Learning & Decision support

CSDL environment for Smart Visualization

Process Layer
Interactive Analysis

Data Layer

Data Storing

Data Restore & Multidimensional Analysis

Data Capture & Update

IS : Information System
ETL : Extracting, Transforming, Loading

CSDL: Collaborative System for Data and Information Literacy

IS : Information System
ETL : Extracting, Transforming, Loading

Data Warehouse

Dimension 1
Dimension 2
Dimension 3
Dimension n

Design Instance

Analysis & Reporting Tools → Decisional System

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Semantic Referent for Data Integration

Interoperability Layer

Integrating

Structuring

Ontology

Content Description Source 1

Content Description Source n

ETL Process

Information System 1

Local DB Schema

Data

Information System n

Local DB Schema

Data

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Common and shared vocabulary

- Structuring and Integrating data extracted from heterogeneous data sources
- Handling Heterogeneous Models
  - Querying heterogeneous models
  - Model Comparison – Transformation – Integration
  - Model Reuse – Composition
  - Model Annotation and traceability
Conclusion

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Conclusion

• Major challenges:
  – Intuitive data representation and interaction in collaborative environments
  – Visualization of uncertainties

• Technologies which need further developments:
  – Surrogates models
  – Model management
  – Exploration techniques (e.g. M-O Optimization)
  – MCDM tools