Visual tools for understanding multi-dimensional parameter spaces

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Overview

- Case Studies
  - Tuner - Image segmentation
  - FluidExplorer - Fluid animation
  - Vismon - Fisheries science
- Abstraction
  - Sampling multi-d spaces
  - Exploring multi-d spaces
  - Trading off multiple objectives
- Challenges

Tuner
Image segmentation

Image Segmentation

- Partitioning the image into disjoint regions of homogeneous properties
- Useful for statistical analysis, diagnosis, and treatment evaluation

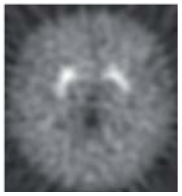
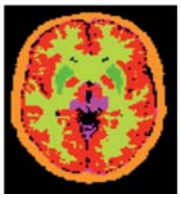


Image Segmentation



Segmentation by Thresholding

Sigma = 1.0

- traditionally - finding edges
- Canny edge detection ... needs thresholds!
  - width of Gaussian
  - low and high thresholds

courtesy of http://www.cs.washington.edu/research/imagedatabase/demo/edge/

Segmentation by Thresholding

Sigma = 2.0

- traditionally - finding edges
- Canny edge detection ... needs thresholds!
  - width of Gaussian
  - low and high thresholds

courtesy of http://www.cs.washington.edu/research/imagedatabase/demo/edge/

Energy functionals

- minimize energy $E(\phi, I)$
- often times:

$$E(\phi, I) = \alpha_1 E_1(\phi, I) + \alpha_2 E_2(\phi, I) + ... + \alpha_k E_k(\phi, I)$$

- where
  - I - input image
  - φ - segmentation
  - α - different weights

The Zen of tuning parameters!

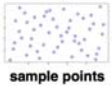
- very tedious and time consuming
- loop over
  - guess a parameter combination
  - wait for segmentation result (often minutes)
  - evaluate result (often visually)
- did we reach a stable parameter region?

Parameter Tuning

Principle ideas

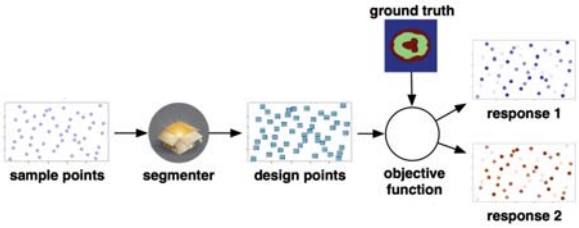
- Assumptions
  - ground truth is given
  - we use a quality measure (e.g. DICE-coefficient or Precision-Recall)
- Requirements
  - No stone unturned
  - Separate the wheat from the chaff
  - Stability

Sampling high-D space

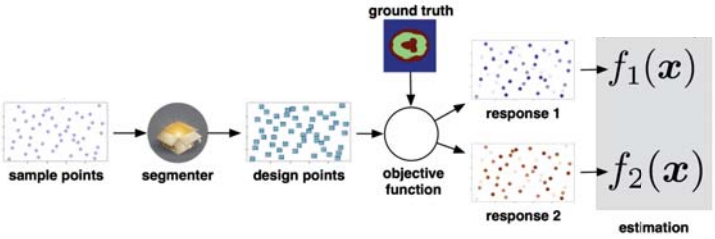


Apply (black-box) Segmentation

Compare to ground-truth

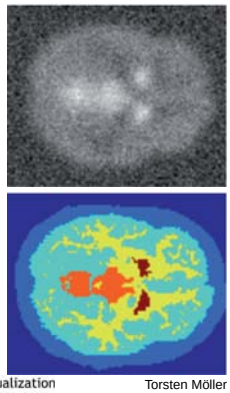


Build an estimator

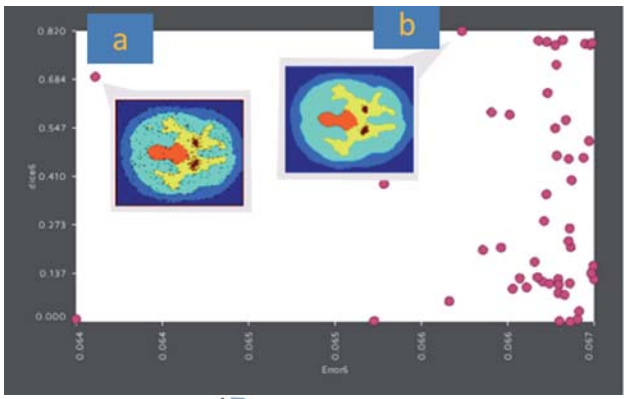


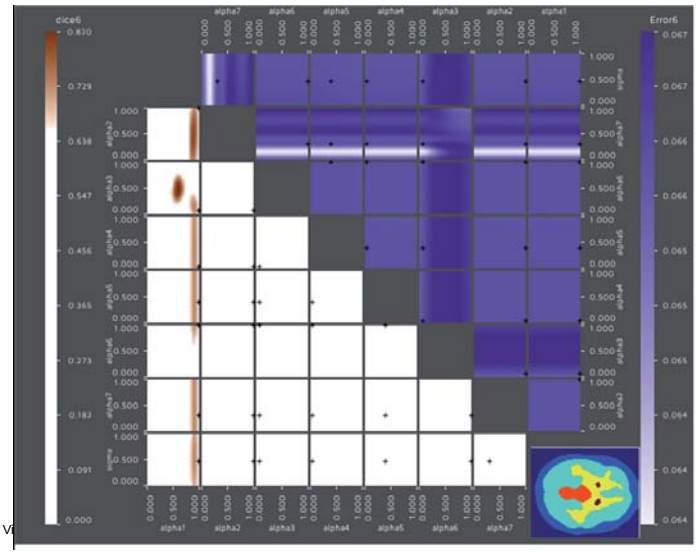
Case study - Brain dynamic PET

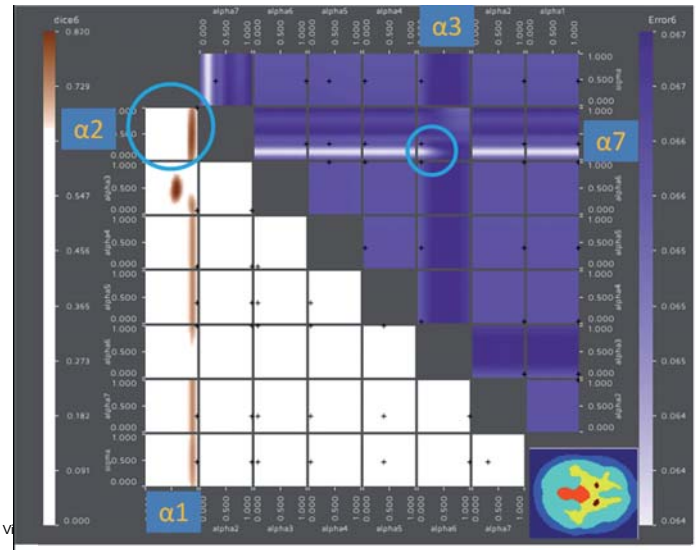
- 46 time steps
- very noisy
- challenging to segment
- 8 energy model to explore

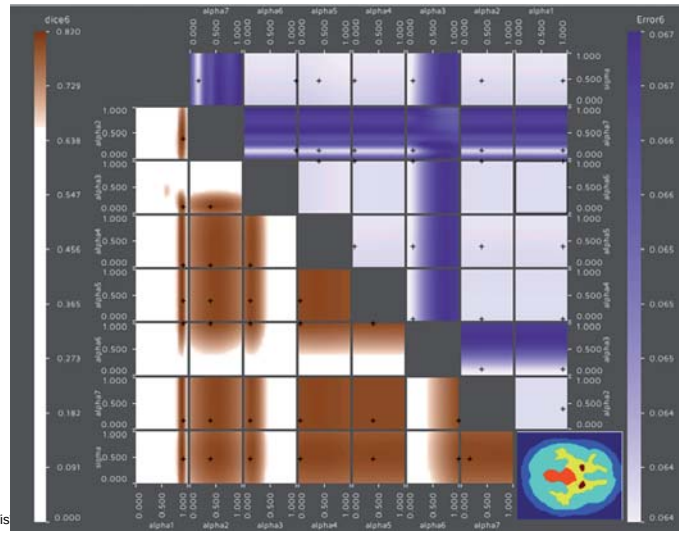


50 samples

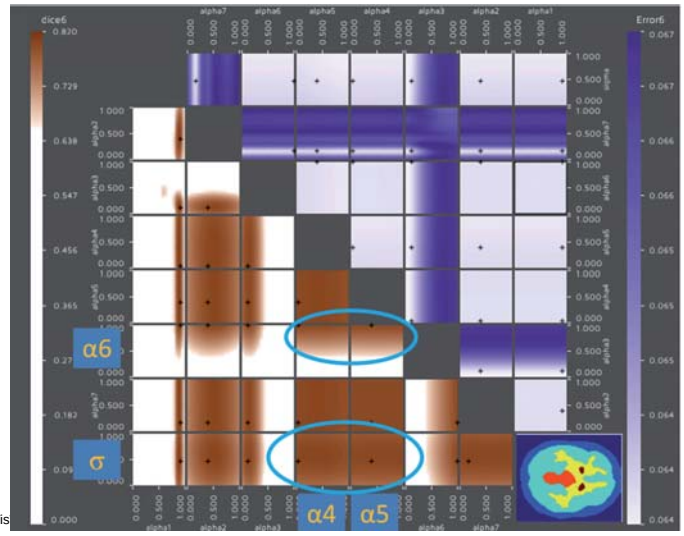




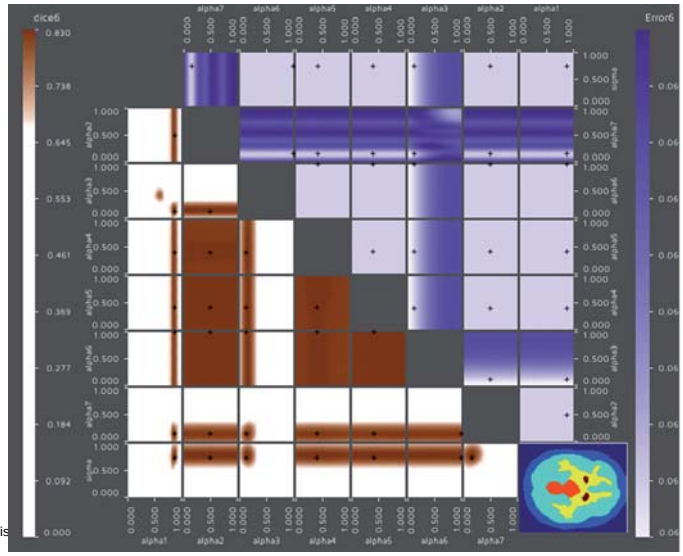




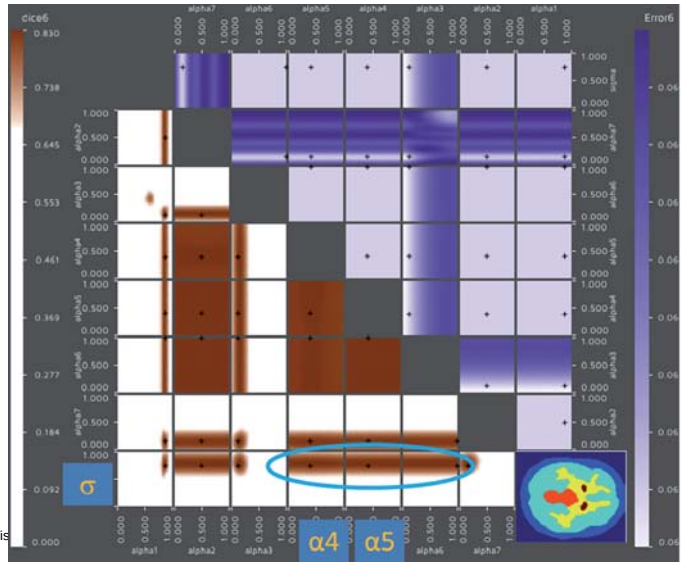
Vis 19



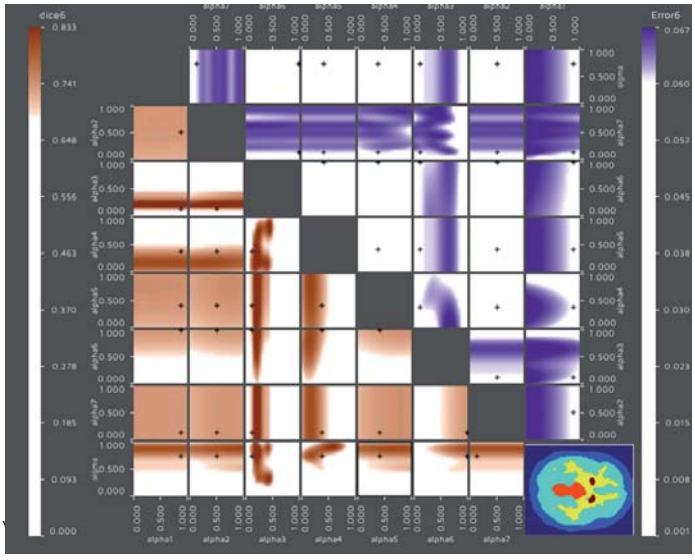
Vis 20



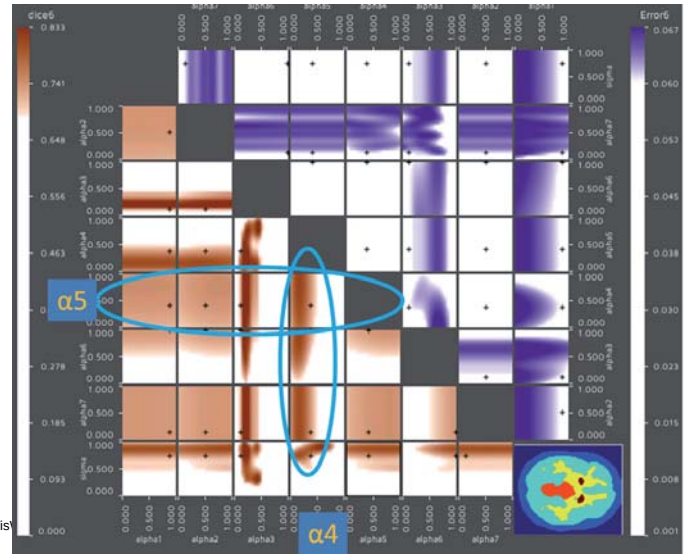
Vis 21



Vis 22



23



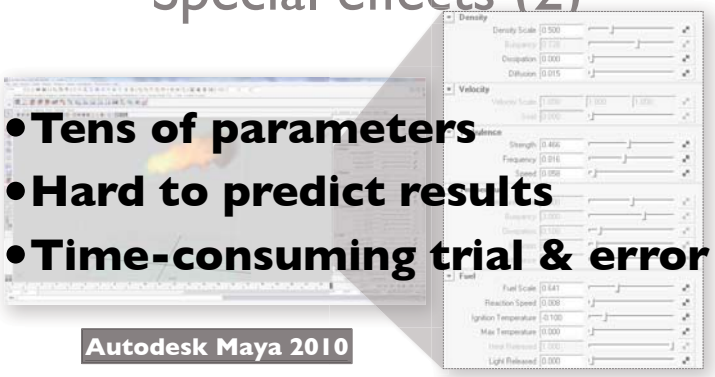
Vis 24

FluidExplorer
Fluid animation

Special effects

- Fluid simulation is heavily used in the motion picture industry
- Most common animation packages include solvers or offer add-ons
- Problem: Difficult to control for visual effects artists

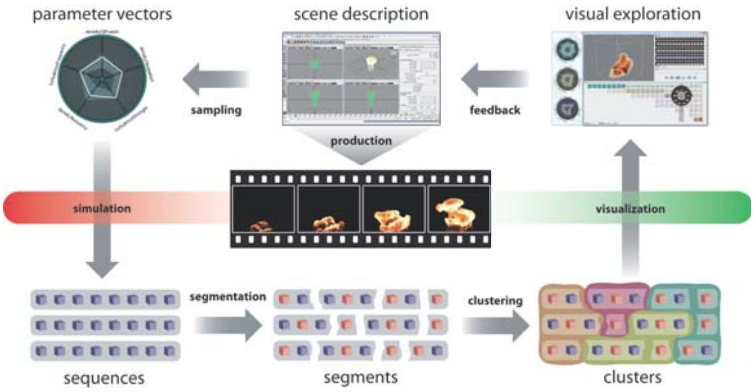
Special effects (2)



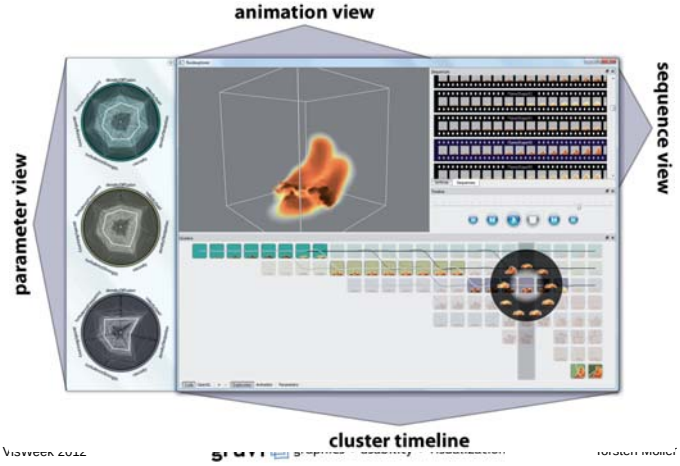
- **Tens of parameters**
- **Hard to predict results**
- **Time-consuming trial & error**

Autodesk Maya 2010

Overview



Visualization



Video

Vismon
Fisheries science

Politics of Fisheries Management

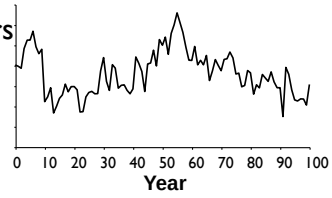
- policymaker goal
  - make well-informed decisions based on large amounts of quantitative information
- changing political context
  - more accountability for decision making
- evolution over time
  - command and control
    - we have the data and we decide
  - decide, announce, defend
    - after push for public consultations
  - multistakeholder consultation
    - new ideal: include many stakeholders in analysis process itself
- new need
  - support not only communication to, but also analysis with, multiple stakeholders

Roles

- fisheries managers
  - choose actions to best meet management objectives
    - maintain sufficient spawners
    - allocate catches among competing interest groups
- stakeholders
  - environmentalists
  - fishing interest groups
    - commercial fishing industry
    - subsistence (First Nations) fishing communities
    - recreational fishers
- fisheries scientists
  - provide fisheries managers with extensive quantitative information to support decision making, via simulation

Simulation

- For each management option
  - Calculated average of each indicator across 500 Monte Carlo trials
- do this over 100 years



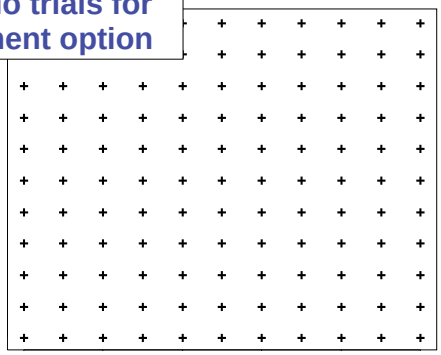
Management Options

- Constant escapement goal (target number of spawners)
- Constant harvest rate on returns that are surplus to the target escapement

Performance Indicators

- Escapement (spawners)
- Subsistence catch
- Commercial catch

500 Monte Carlo trials for each management option



Harvest rate on run exceeding target spawners

Target spawners (in 1000's)

Yukon R. fall chum salmon

Average spawners (1000s)

8	16	62	192	299	380	443	500	546	593	621
12	23	98	245	338	415	479	531	572	601	634
18	35	149	290	387	451	509	554	600	624	652
24	54	212	352	437	494	546	586	613	643	667
45	96	296	419	488	538	580	615	645	664	670
90	202	391	480	541	585	624	643	662	678	687
189	358	497	562	601	629	642	670	686	687	696
403	522	592	622	643	661	677	688	700	705	700
585	630	653	669	681	693	698	710	718	717	712
676	679	686	699	702	704	704	717	718	722	715
693	693	691	703	705	706	705	718	719	722	716

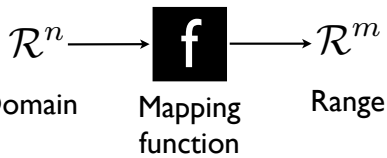
Harvest rate on run exceeding target spawners

Target spawners (in 1000's)

Demo

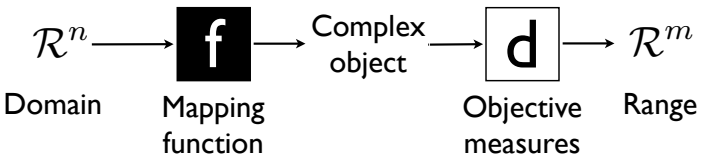
Abstraction

- abstracted (black-box) scheme:



- we can tell **Inputs** from **Outputs**
- we can query this box at every "point"

- abstracted (black-box) scheme:



- we can tell **Inputs** from **Outputs**
- we can query this box at every "point"

Inputs

- well chosen by the scientist, i.e. people care about their inputs
- normally continuous (quantitative data)
  - need to sample the space
- categorical data common too (e.g. use of a different algorithm)

Input groupings

- experimental design literature:
  - control variables (or engineering v. or manufacturing variables) are variables the user has a direct input on
  - environmental variables (or noise variables) are variables specific to the environment of the design and can be measured in the real world (e.g. temperature)
  - model parameters (or tuning parameters) describe the uncertainty in the mathematical modeling (e.g. thresholds)

Outputs

- typically very complex, e.g.
  - 2D, 3D images (Tuner)
  - animations (FluidExplorer)
  - performance graphs (fuel cells)
  - social networks
  - robot simulation (Player/Stage)
- hard to evaluate / compare many complex outputs

Objective measure

- one-dimensional ("goodness") rating: d(object) = quantitative grade
- two-dimensional comparison: $d(O_1, O_2)$ = quantitative similarity
- objective measures can be
  - exact (reliable)
  - approximate - about right, but not 100% precise
  - unknown (active learning)

Tasks that arise

- Optimization
- Partitioning / Grouping
- Fitting
- Steering
- Sensitivity

Task 1 - Optimization

"Find the best parameter combination given some objectives."

- objectives need to be formulated (as an objective function)
- often times multiple objectives that need to be balanced
  - one: no Vis, just use some optimization toolbox
  - two: Pareto analysis (e.g. Tuner)
  - multiple: facilitate multi-objective trade-off (e.g. Vismon)

Task 2 - Segmentation

"How many different types of behaviors are possible?"

- essentially find a segmentation (or clustering) of the output space
- apply to input space
- user wants to know the parameter combinations (and ranges) that create one particular output behavior
- e.g. ParaGlide

Task 3 - Fitting

"Where in the parameter space fall actual measured data?"

- Data fitting - given real inputs and their outputs, improve the understanding / modeling
- Inverse Problem (level sets) - given ONLY the outputs, what inputs would yield this behavior?
- could be formulated as an optimization problem
- e.g. HyperMoVal

Task 4 - Steering

User wants to change the parameter settings during the simulation run.

- control variables - typically no steering (afaik)
- environmental variables - "simulation steering" (e.g. real-time simulators, like {flight, ship, driving}-simulators, or World Lines)
- model / tuning parameters - "computational steering" (e.g. change the grid size, time-stepping, etc.) OR when simulation is expensive, watch while running and stop if no insight

thanks to Andreas Gerndt

Task 5 - Sensitivity

- cross-cutting through all other tasks
- Optimization - "How stable are my optimal parameter settings?"
- Segmentation - "How quick/slow are the transition from one behavior to another?"
- Fitting - "How close does the simulation come to the actual measured data?"
- Steering - not so sure, no experience

Challenges

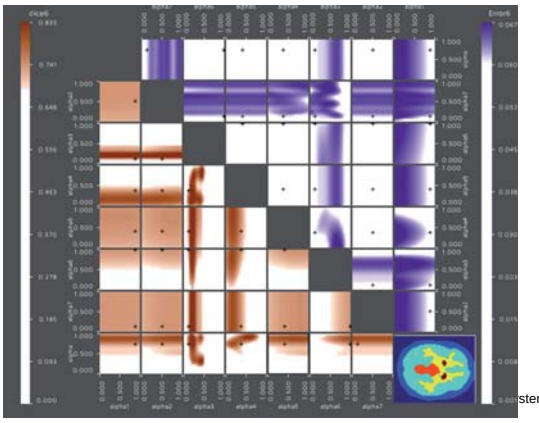
It is a ...

- sampling problem
- rendering problem
- cognitive problem
- design problem
- interface problem

Sampling

- trading-off time and accuracy
- time - would like to get an answer in less than a day (samples are expensive!)
- accuracy - would like to have as dense a sampling as possible
- typically reconstruct / infer values at non-sampled values from sampled neighbors

Rendering



Cognition

- how to understand multi-dimensional spaces?
- facilitating sensitivity
- facilitating trade-offs

Design

- every application is different - user-centered design!
- understanding the goals of the users, employing the tool and refining the design can be a long-haul
- facilitating the discourse during decision making
  - Vismon: managers vs. commercial vs. subsistance
  - FluidExplorer: animator vs. supervisor

Interface

- navigating multi-dimensional spaces
- slices vs. scatterplots
- multi-dimensional Pareto panels
- specifying neighborhoods in multi-dim

Summary

- understanding parameter space - an essential task of computational science
- understanding trade-off of multiple objectives is tough
- "This reduced the work of days to a couple of hours."

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