Visual tools for understanding multi-dim. parameter spaces

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Quiz

- "Each match must agree within 15 degrees orientation, $\sqrt{2}$ change in scale, and 0.2 times maximum model size in terms of location. If fewer than 3 points remain after discarding outliers, then the match is rejected."
- Lowe, 1999, Object recognition from local scale-invariant features (SIFT);
  14,000 citations

Overview

- Case Studies
  - Vismon - Fisheries science
  - FluidExplorer - Fluid animation
- Abstraction
  - Problem abstraction
  - Tasks
  - Strategies
- Challenges

Overview

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Vismon
Fisheries science

The Arctic-Yukon-Kuskokwim (AYK) region

Roles - old days

Scientists

Managers

Goal

Data-driven decision making

Simulation worksheet

Scientists

Managers

Goal:
move data-driven decision making from scientists to managers

Roles

Data-driven decision making

Managers

Simulation data

Interests

Goal:

move data-driven decision making from scientists to managers

Scientists

Stakeholders

Alaskan Salmon Model

Harvest Rate

Escapement

Bill Reid, Haida Dog Salmon - Skaagi, 1974. © Bill Reid Estate

Stochastic

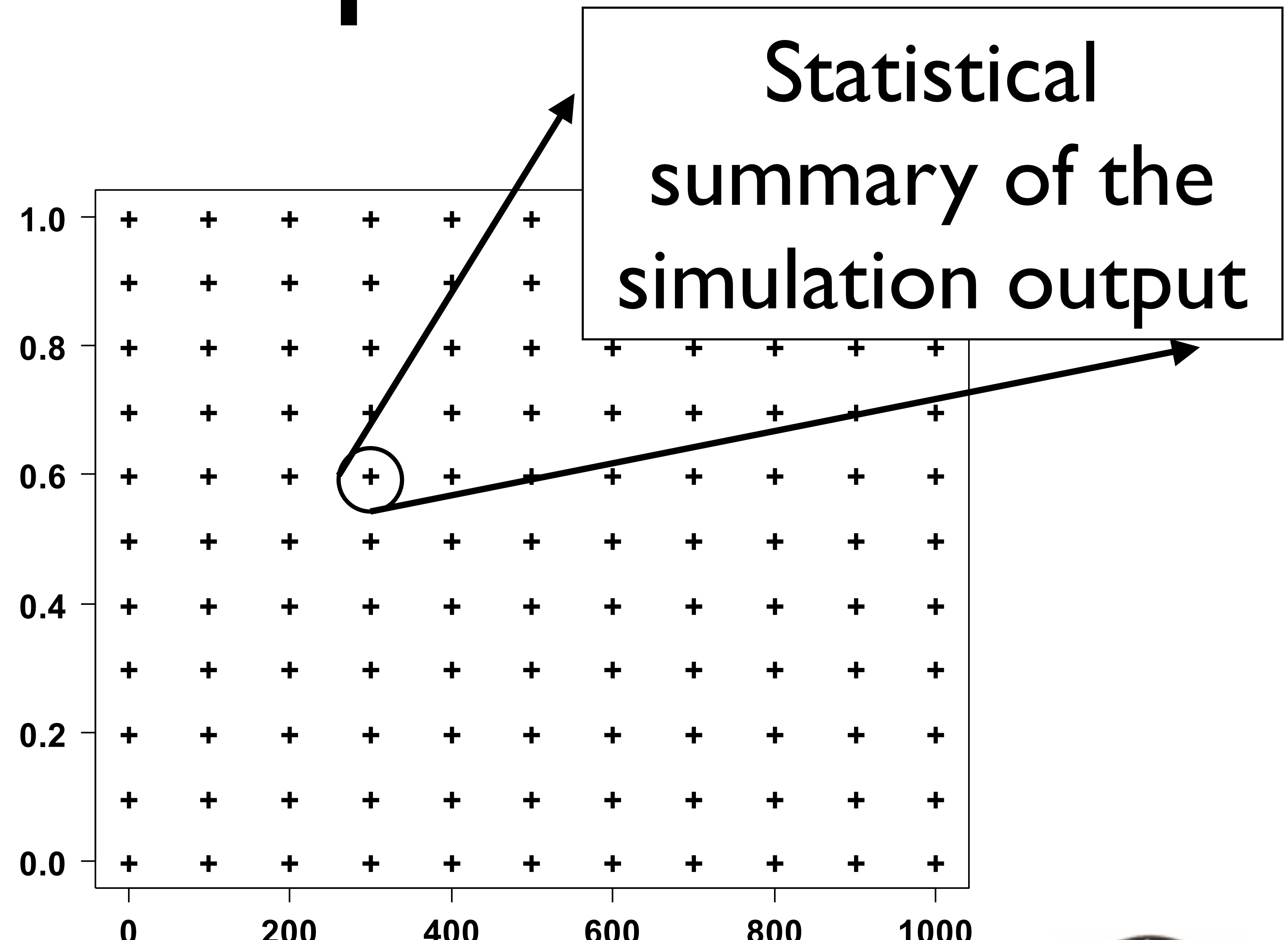
Spawners

Food

$

Scenario: 2 input values

Harvest rate



Escapement (in 1000's)

Output summarized ...

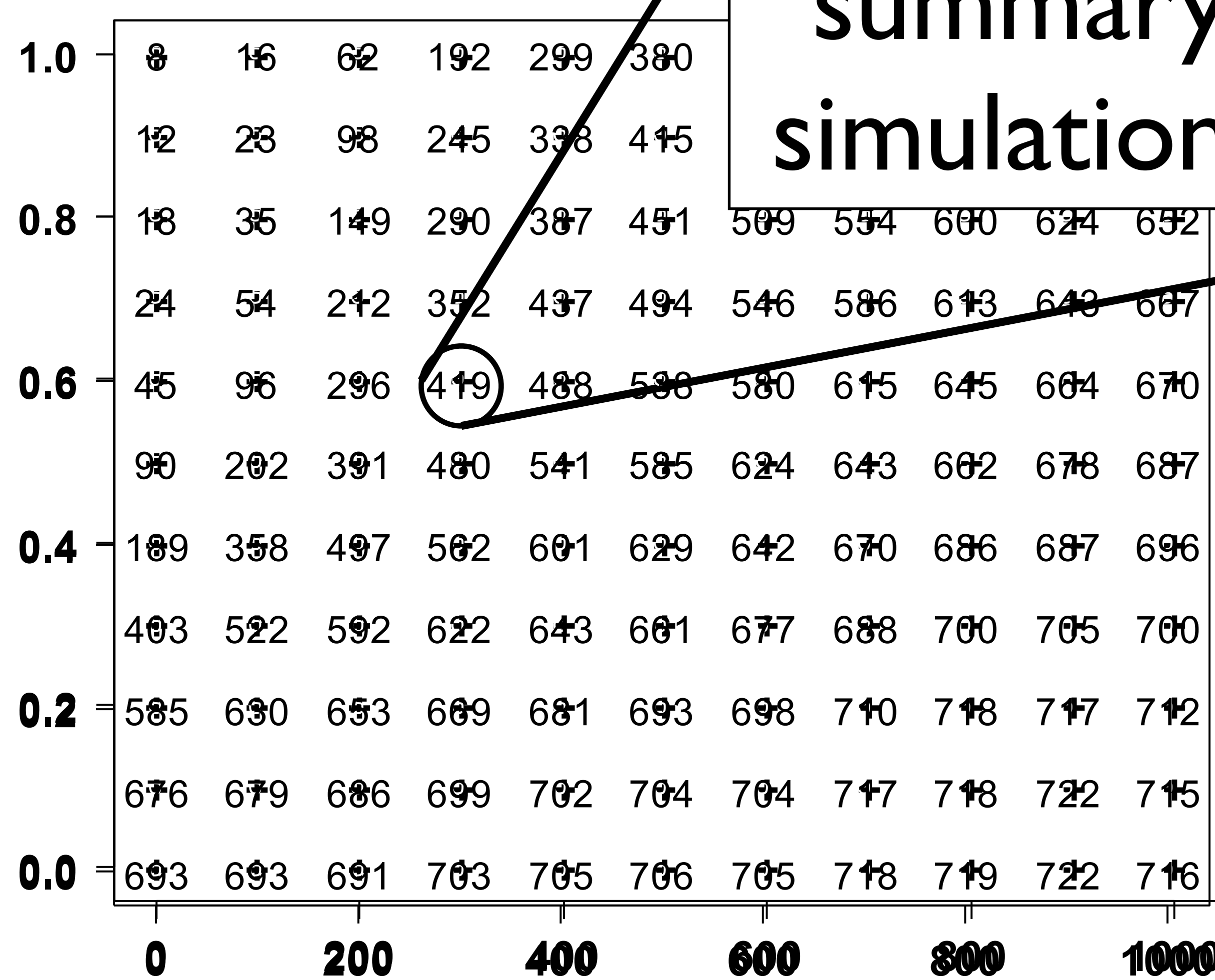
Statistical summary of the simulation output

- Average
- Median
- Coefficient of variation
- % of years something bad happens

Scenario: 2 input values

Statistical summary of the simulation output

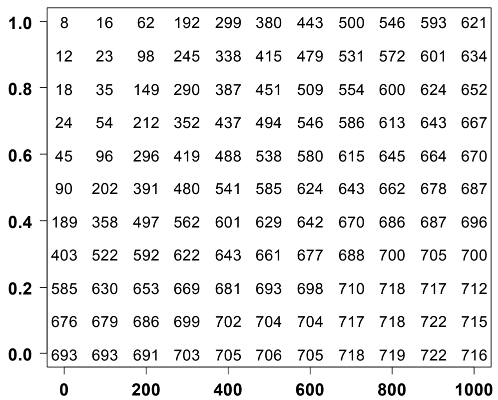
Harvest rate



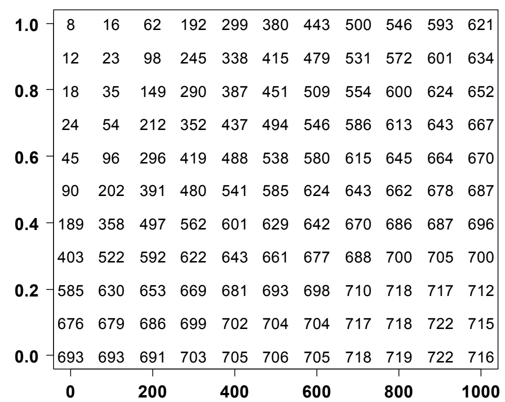
Escapement (in 1000's)

Scenario: 2 input values

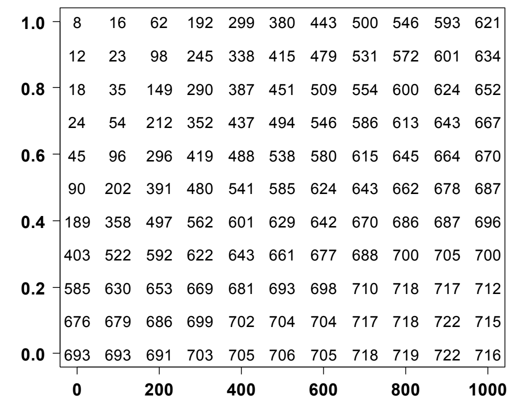
Avg



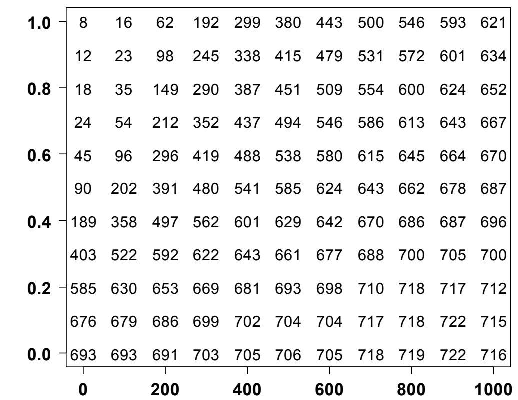
Median



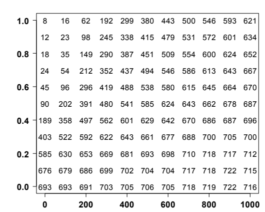
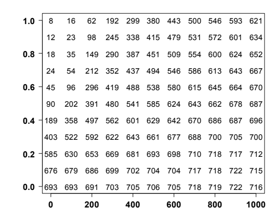
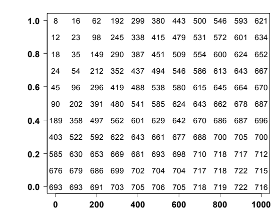
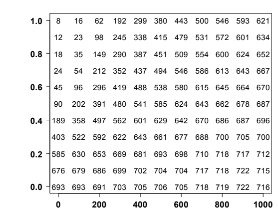
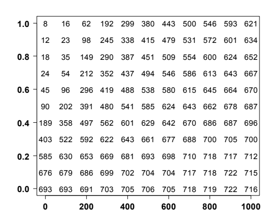
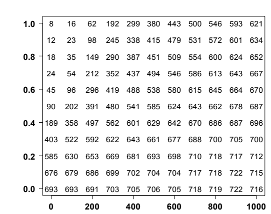
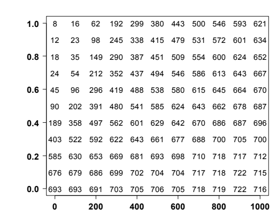
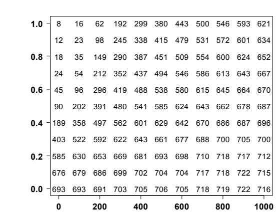
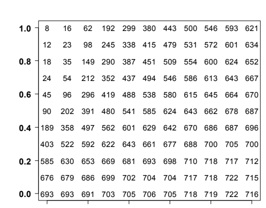
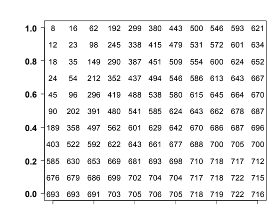
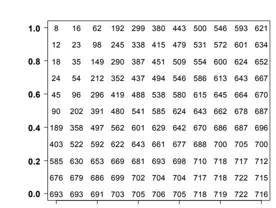
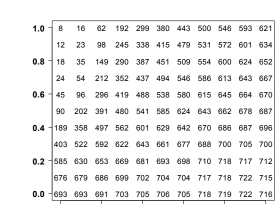
CV



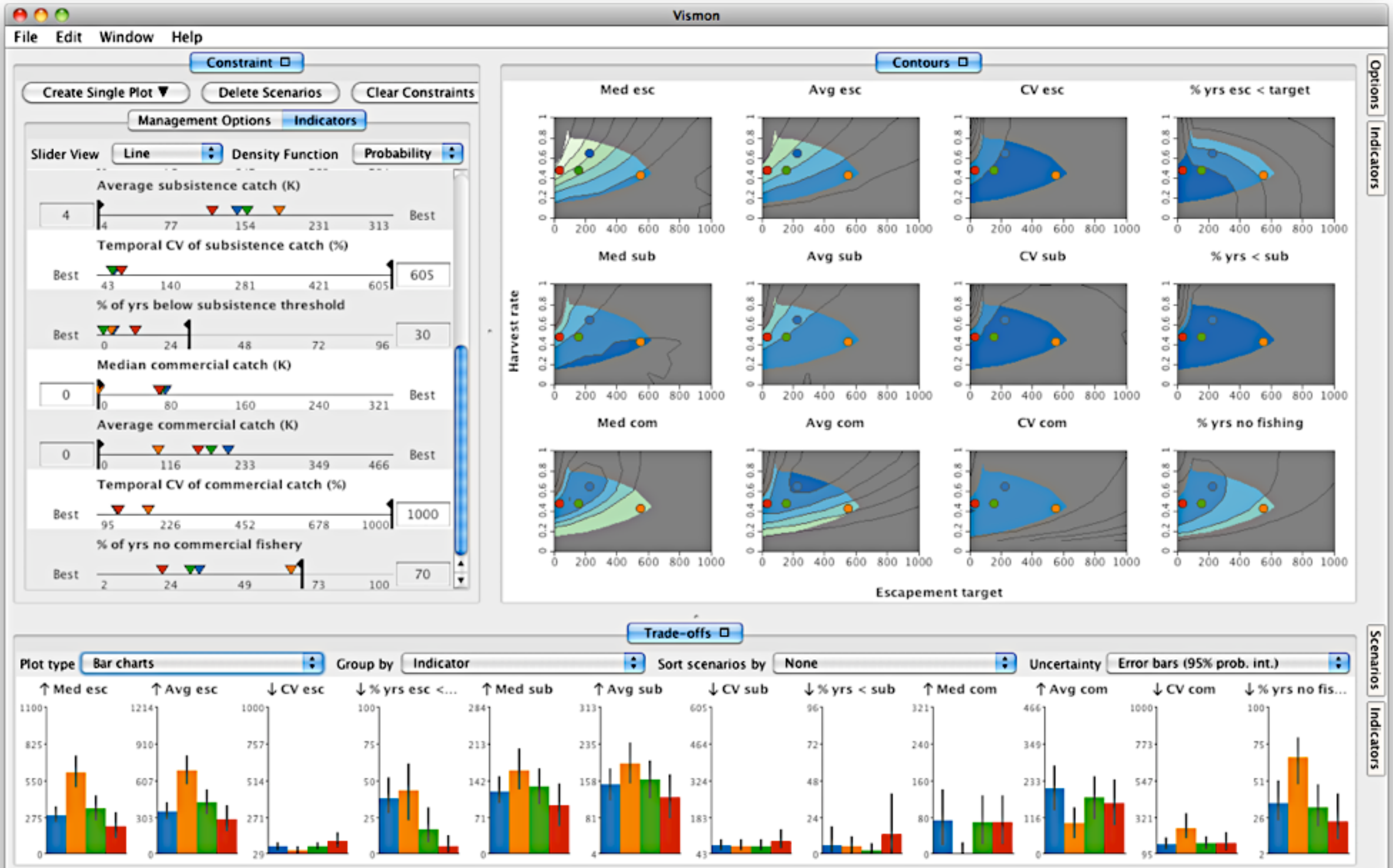
%



12 Outputs / Indicators

	Avg	Median	CV	%
Spawners (Escapement)				
Food (subsistence)				
$ (commercial)				

Vismon



Vismon
File Edit Window Help
Constraint
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Clear Constraints
Management Options
Indicators
Slider View
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Density Function
Probability
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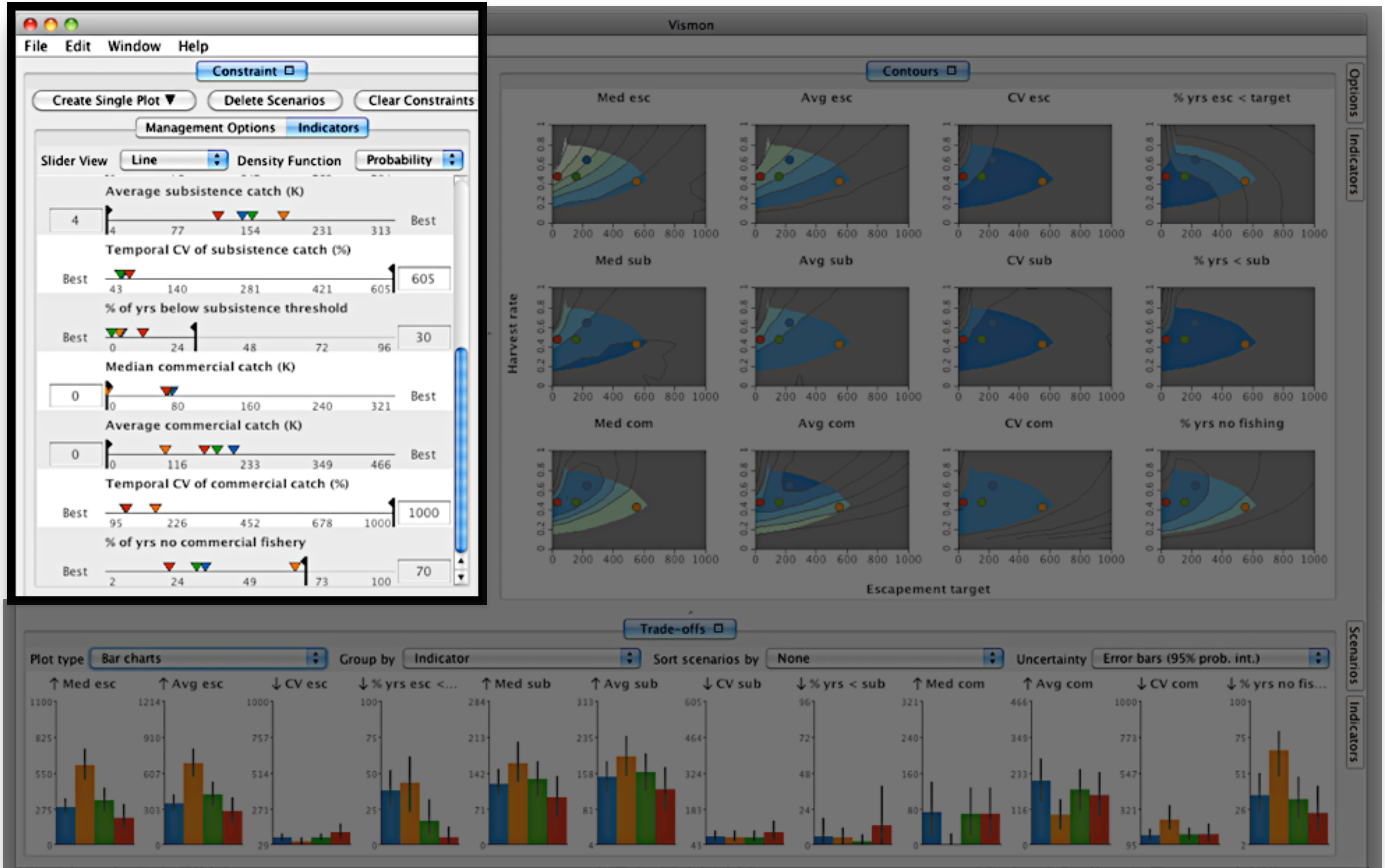
Average commercial catch (K)
Temporal CV of commercial catch (%)
% of yrs no commercial fishery
Best
Contours
Med esc
Avg esc
CV esc
% yrs esc < target
Med sub
Avg sub
CV sub
% yrs < sub
Med com
Avg com
CV com
% yrs no fishing
Harvest rate
Escapement target
Trade-offs
Plot type
Bar charts
Group by
Indicator
Sort scenarios by
None
Uncertainty
Error bars (95% prob. int.)
Options
Indicators
Scenarios

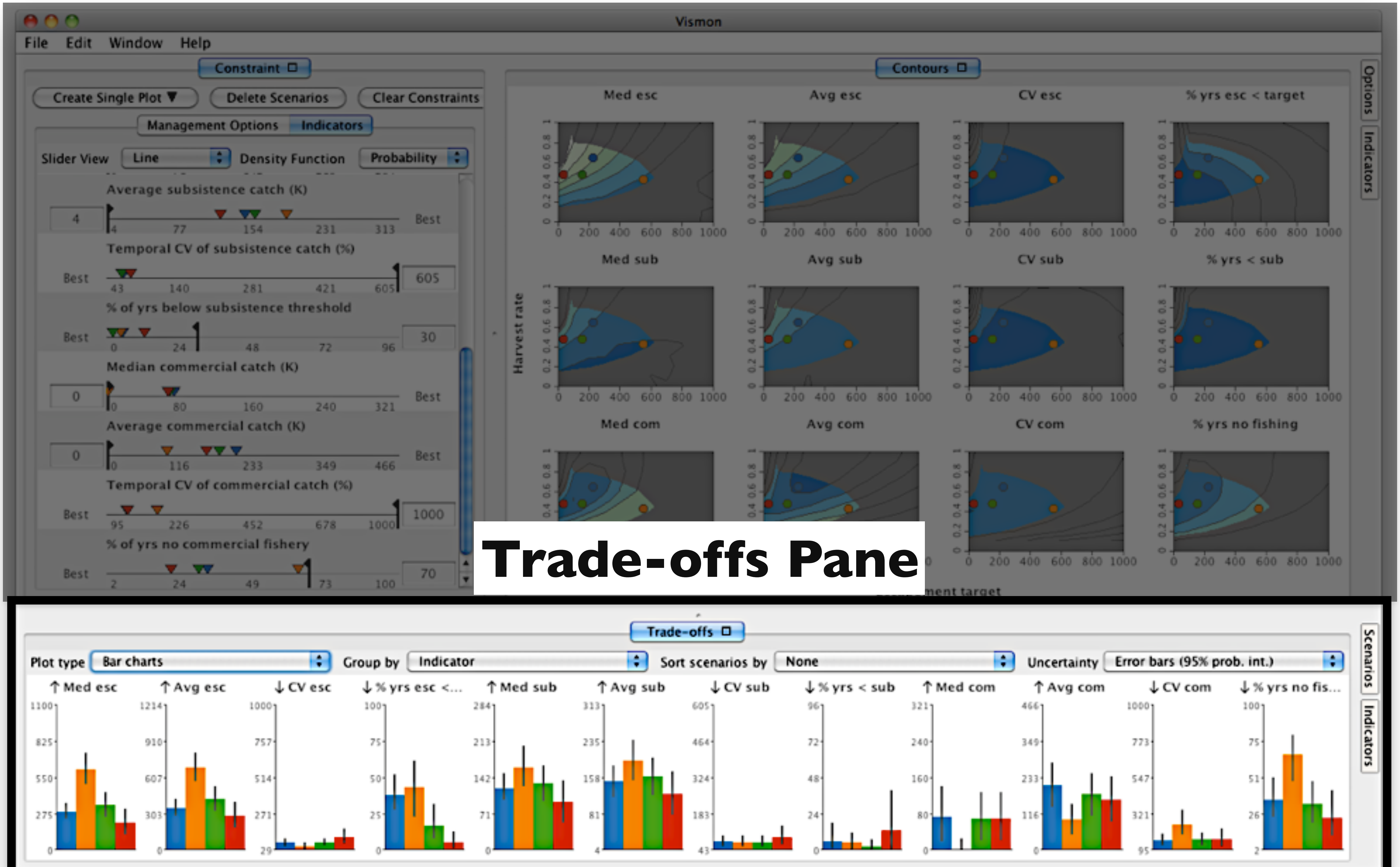
Vismon **Contours Pane**

Vismon

Constraint Pane



Vismon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Med com
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Indicators
Trade-offs Pane
Trade-offs
Plot type
Bar charts
Group by
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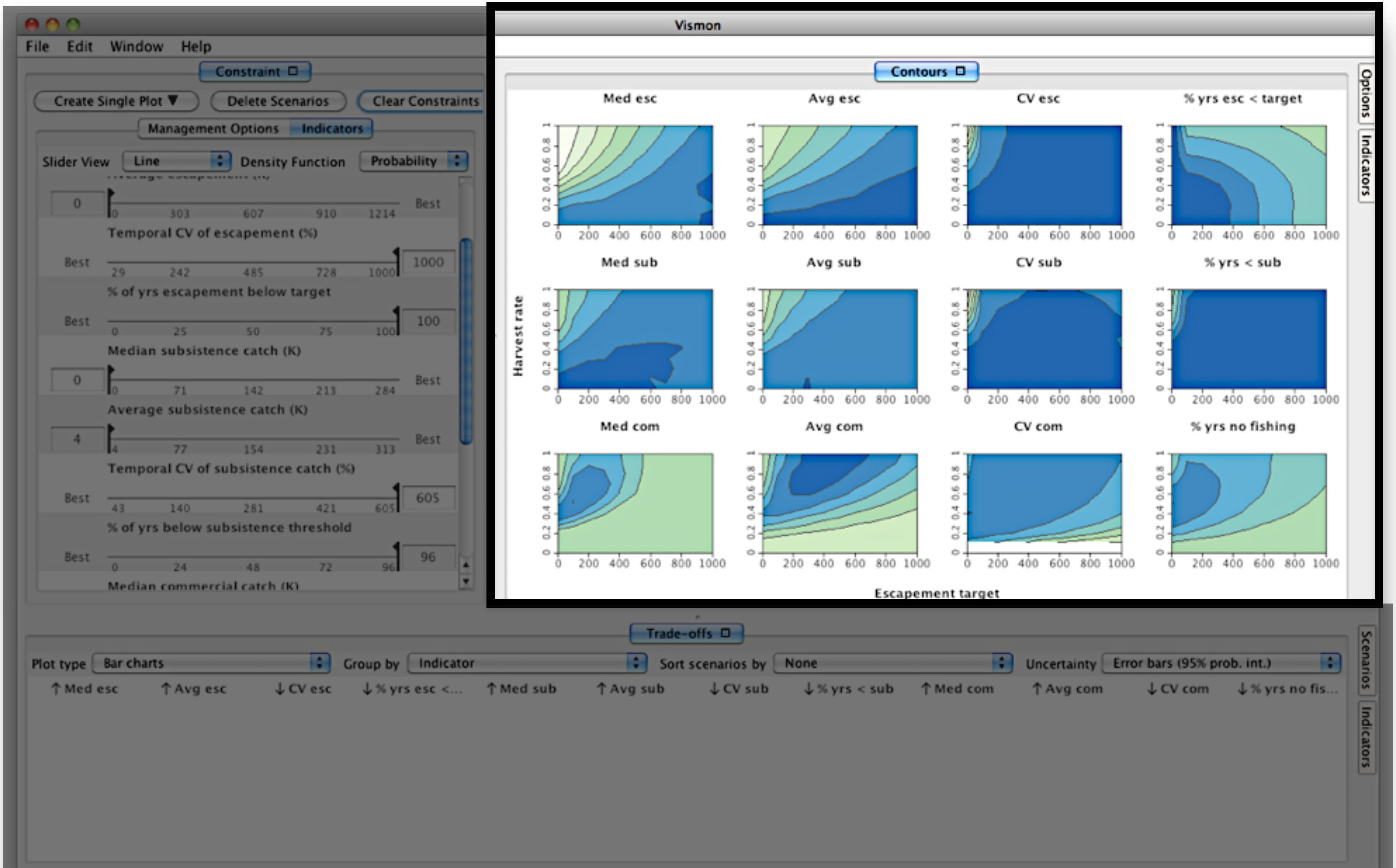
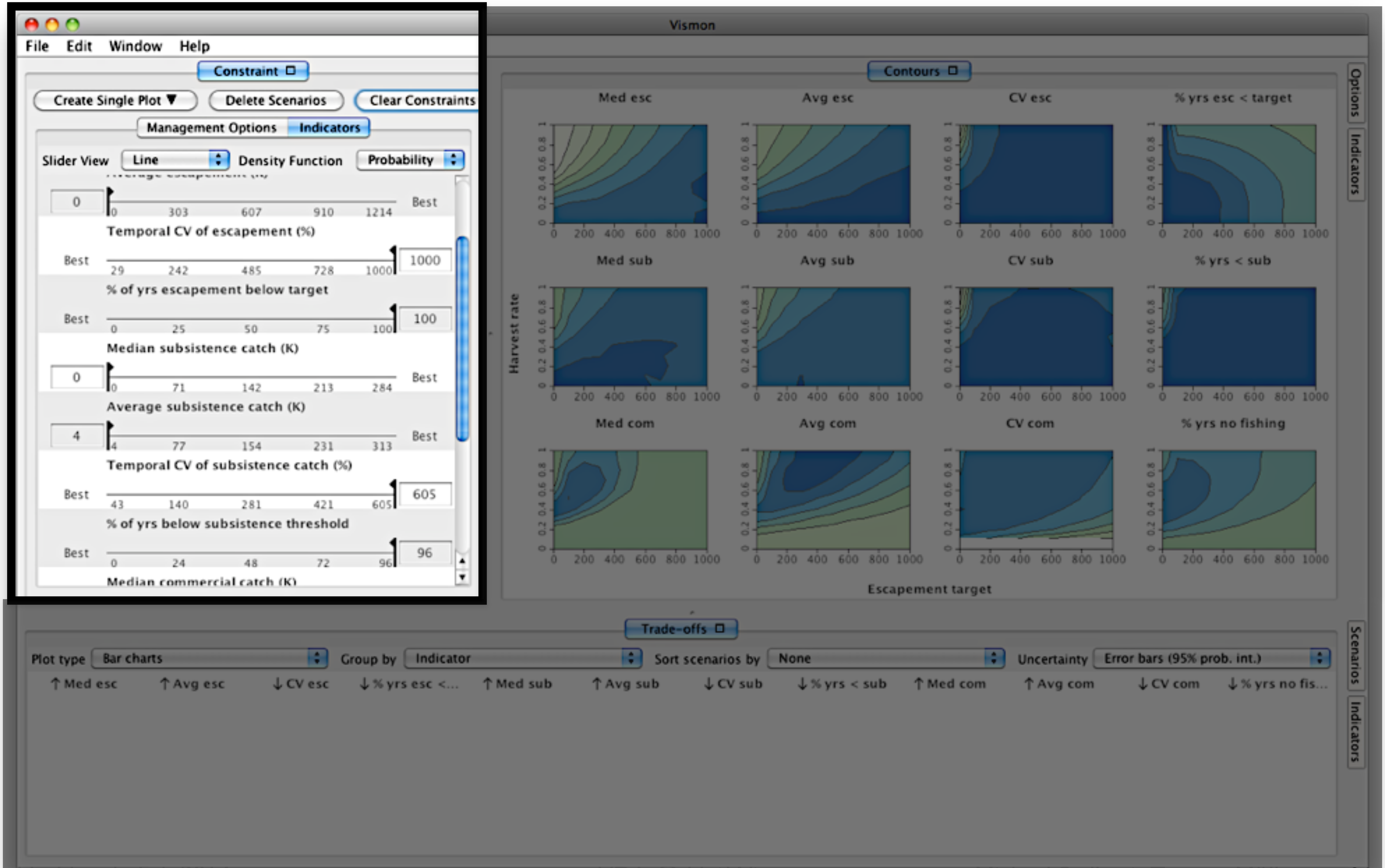
Sort scenarios by
None
Uncertainty
Error bars (95% prob. int.)
Scenarios

Summarization



Constraining



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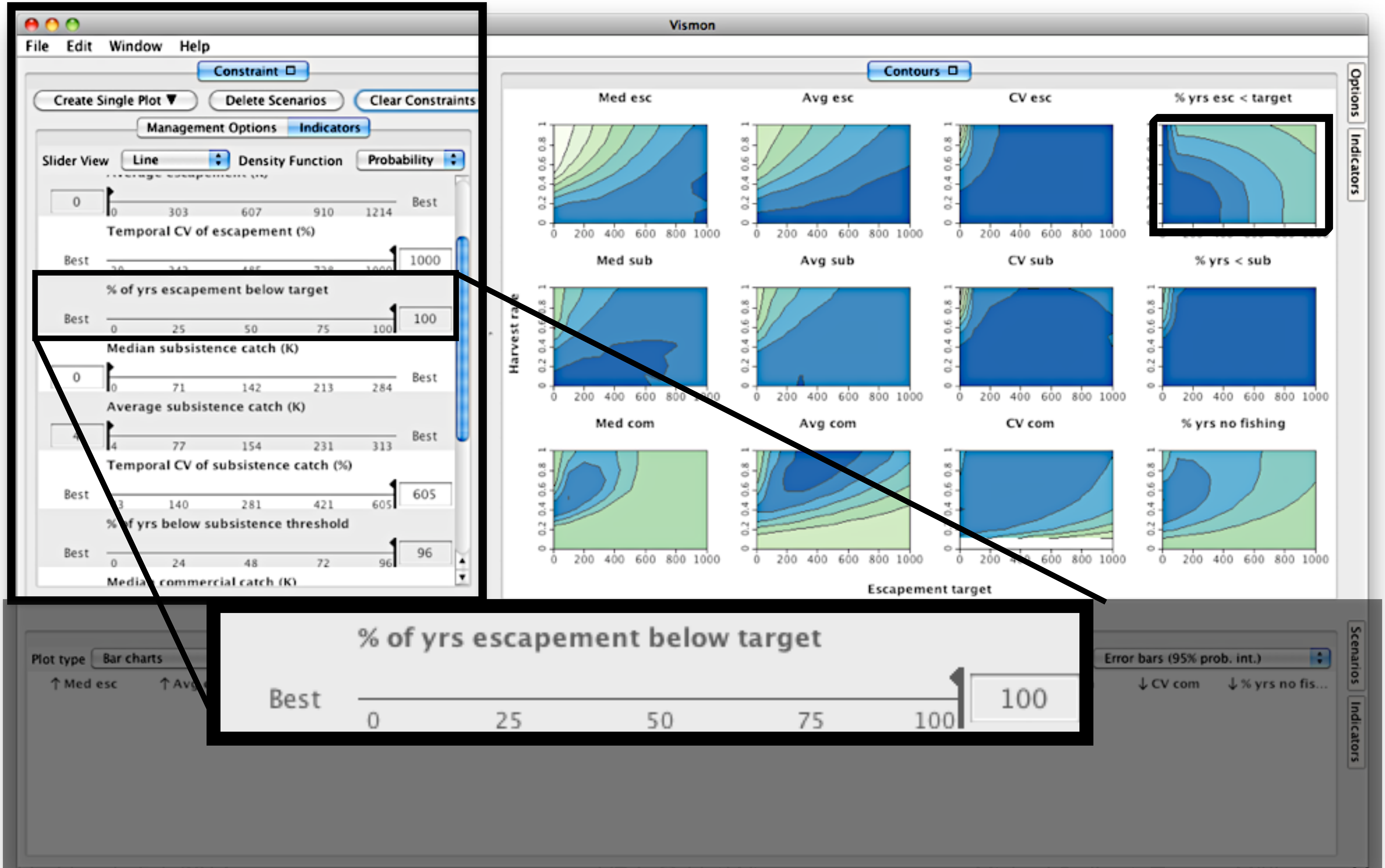

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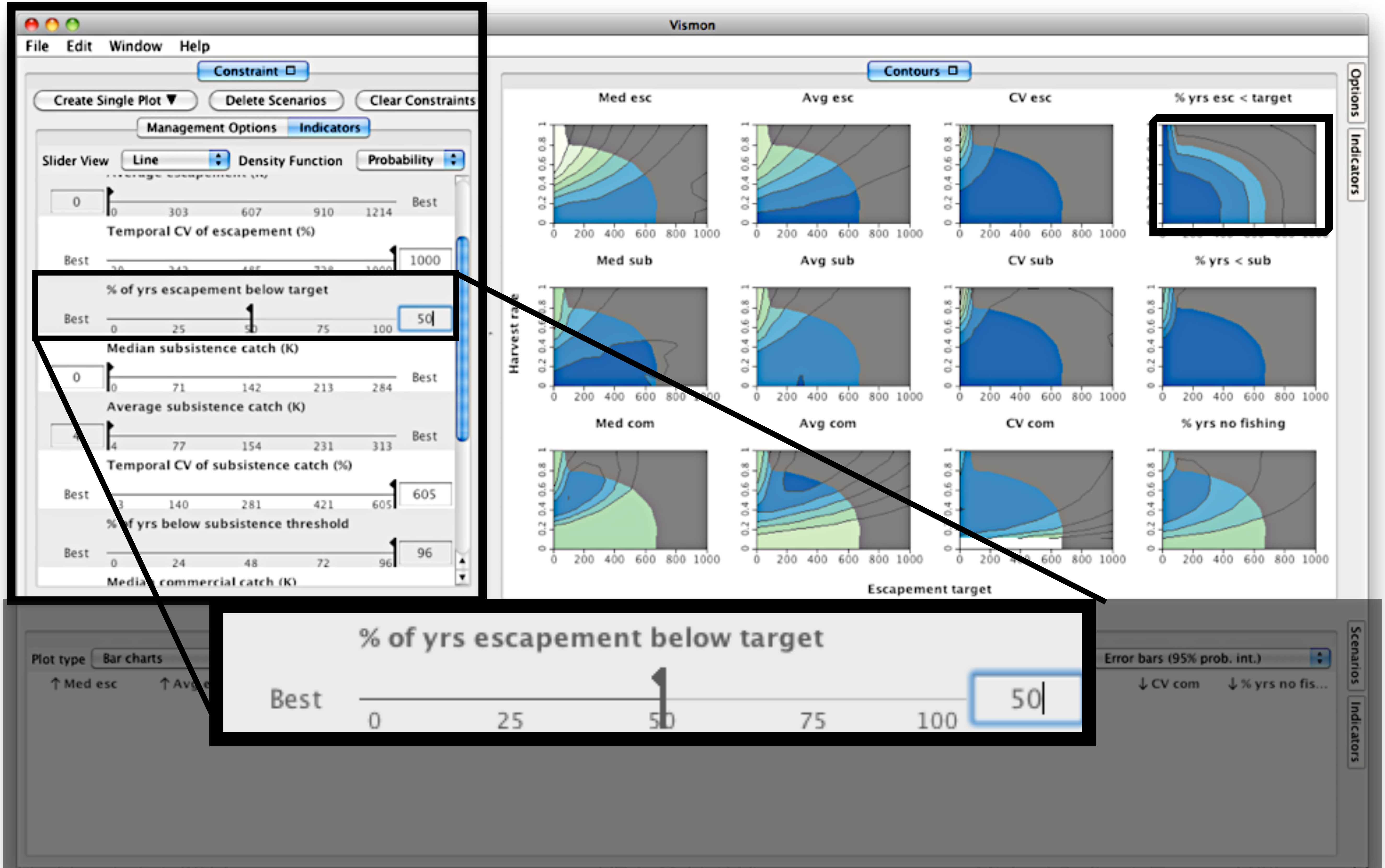

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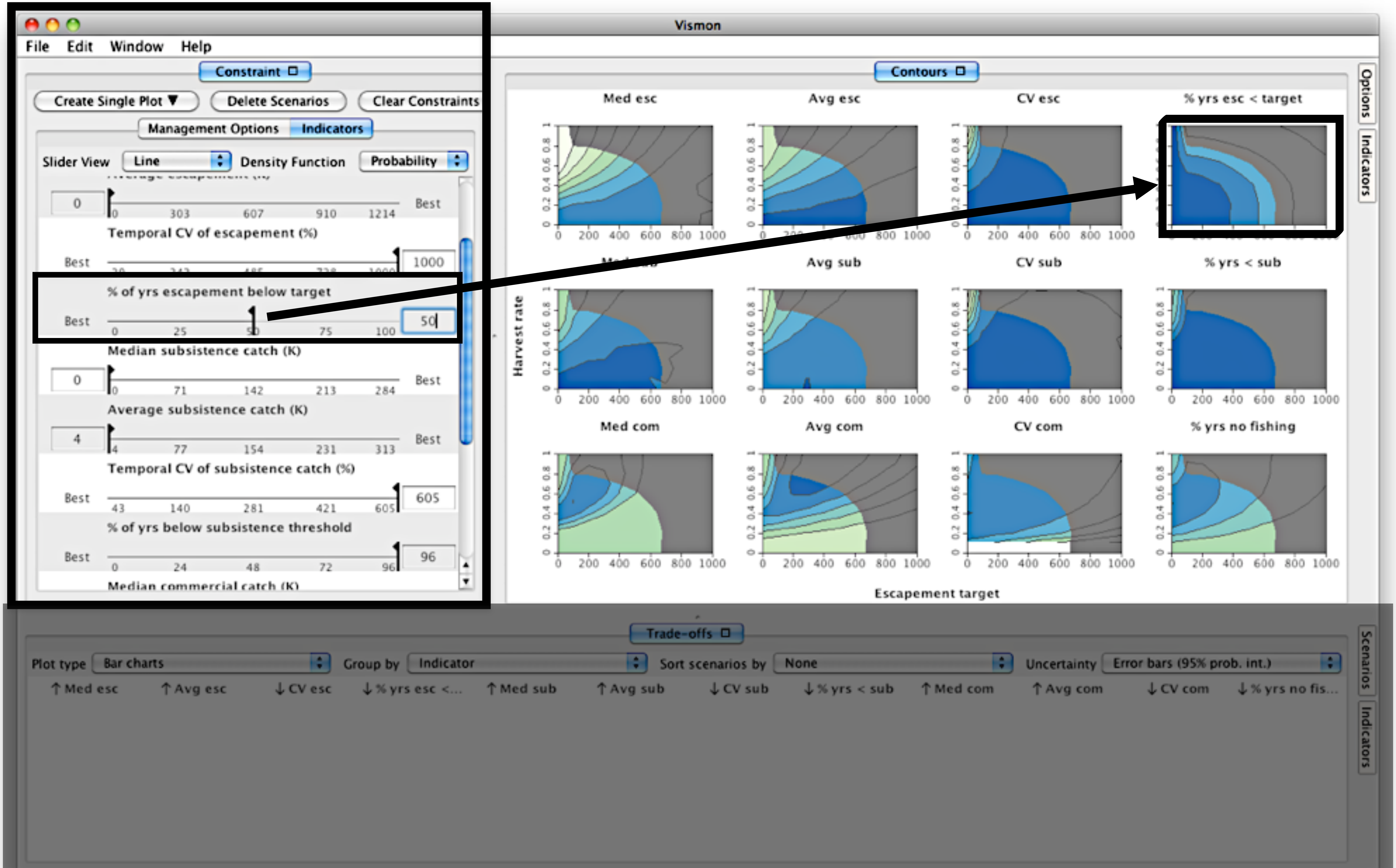

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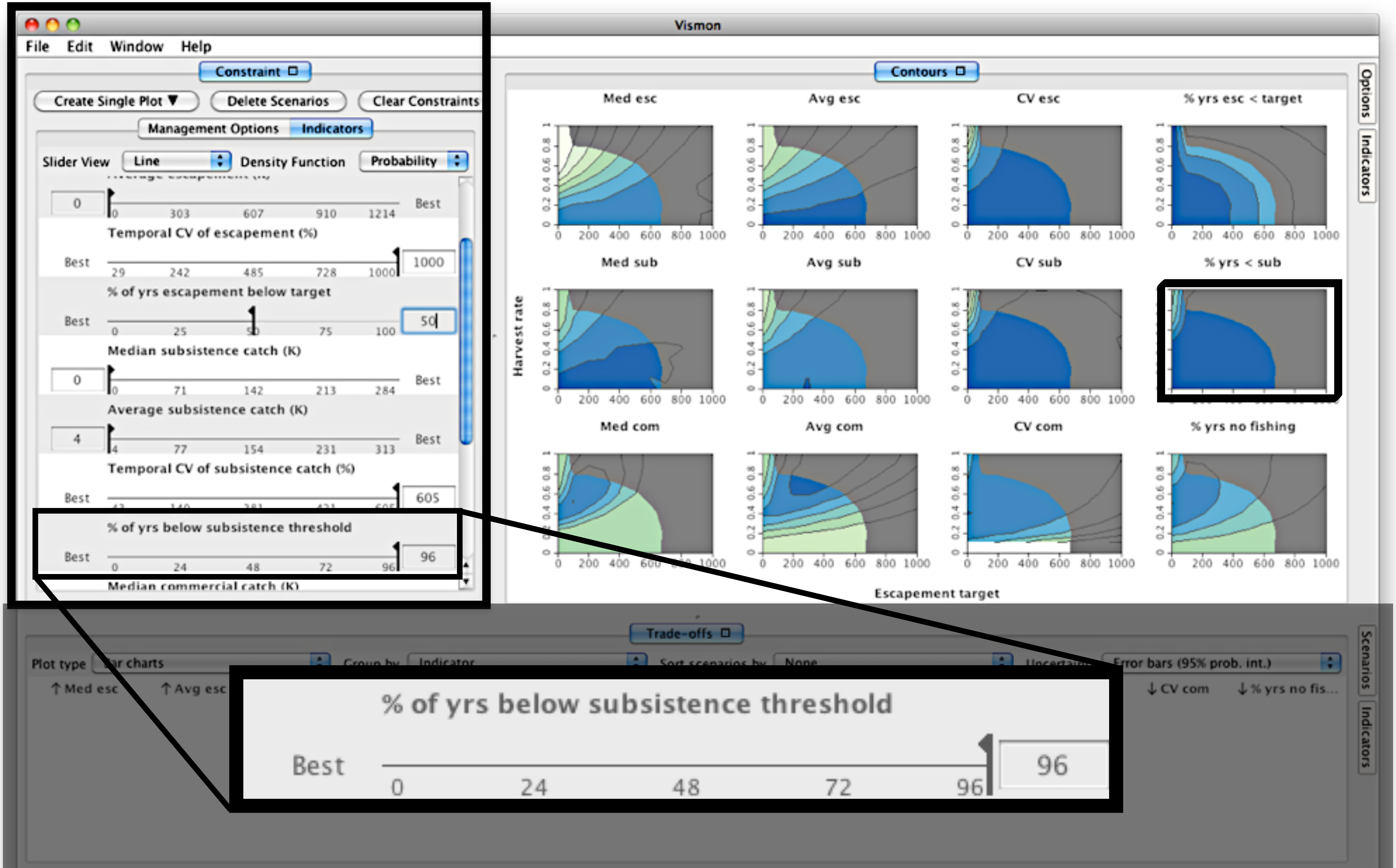

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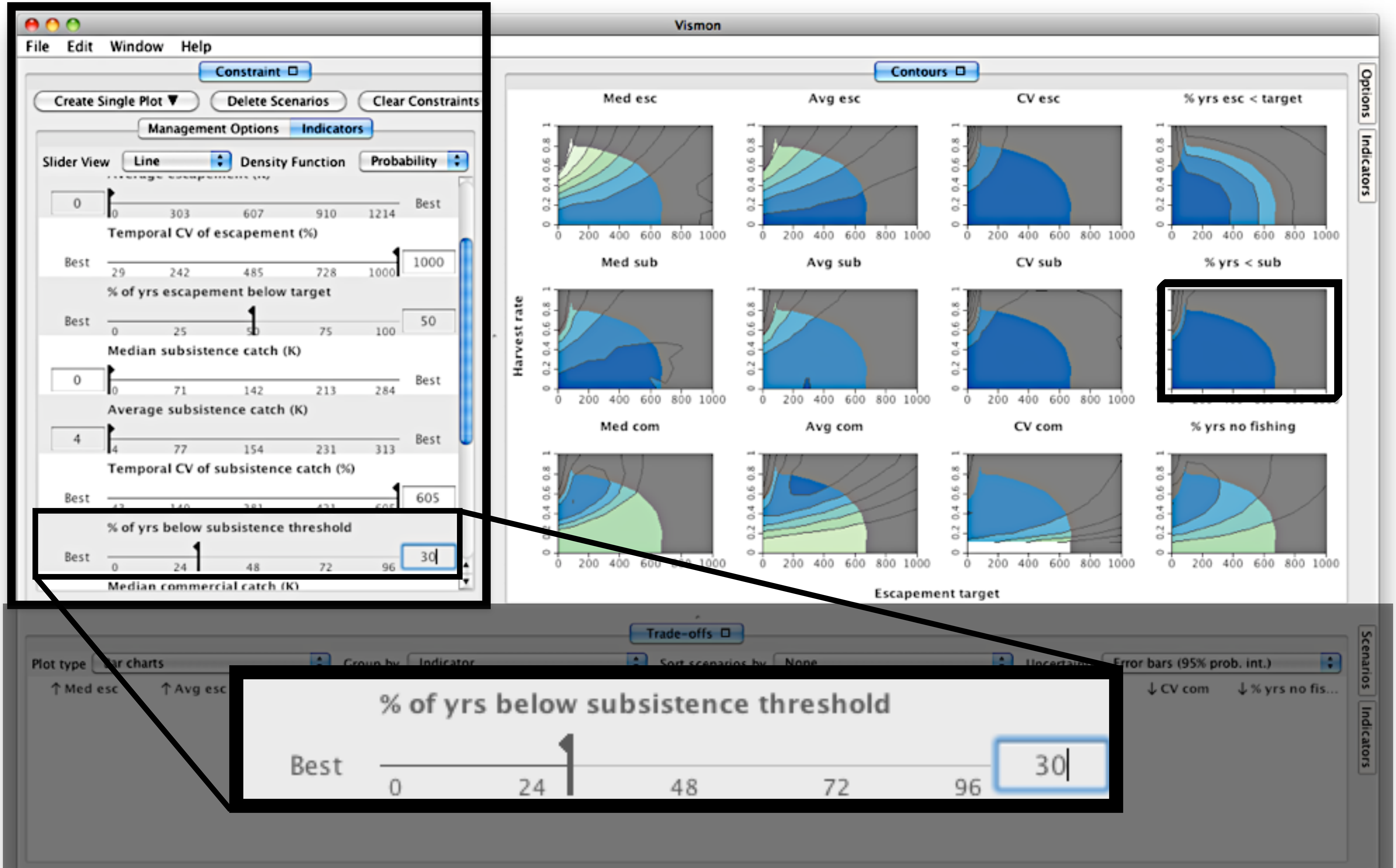

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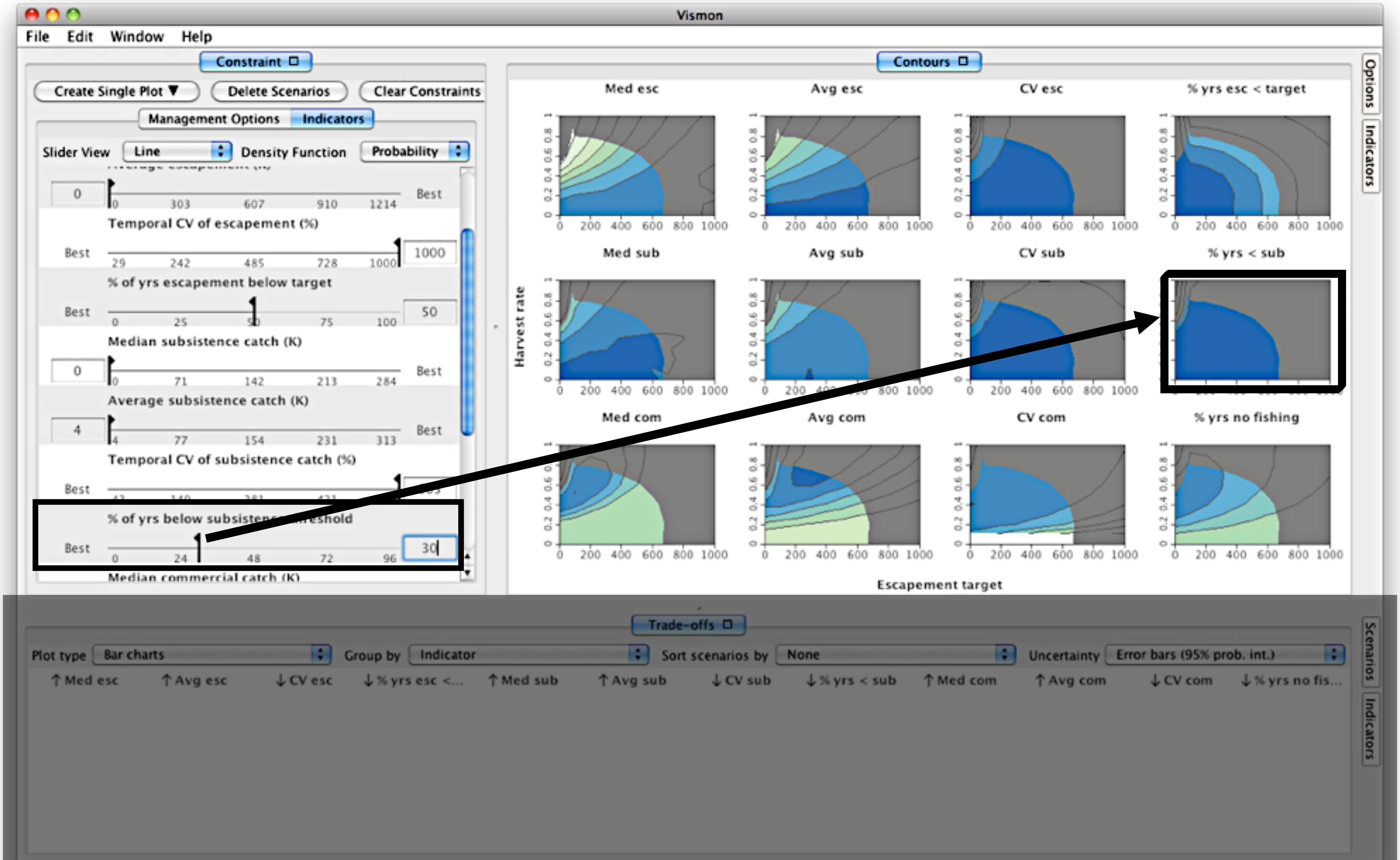

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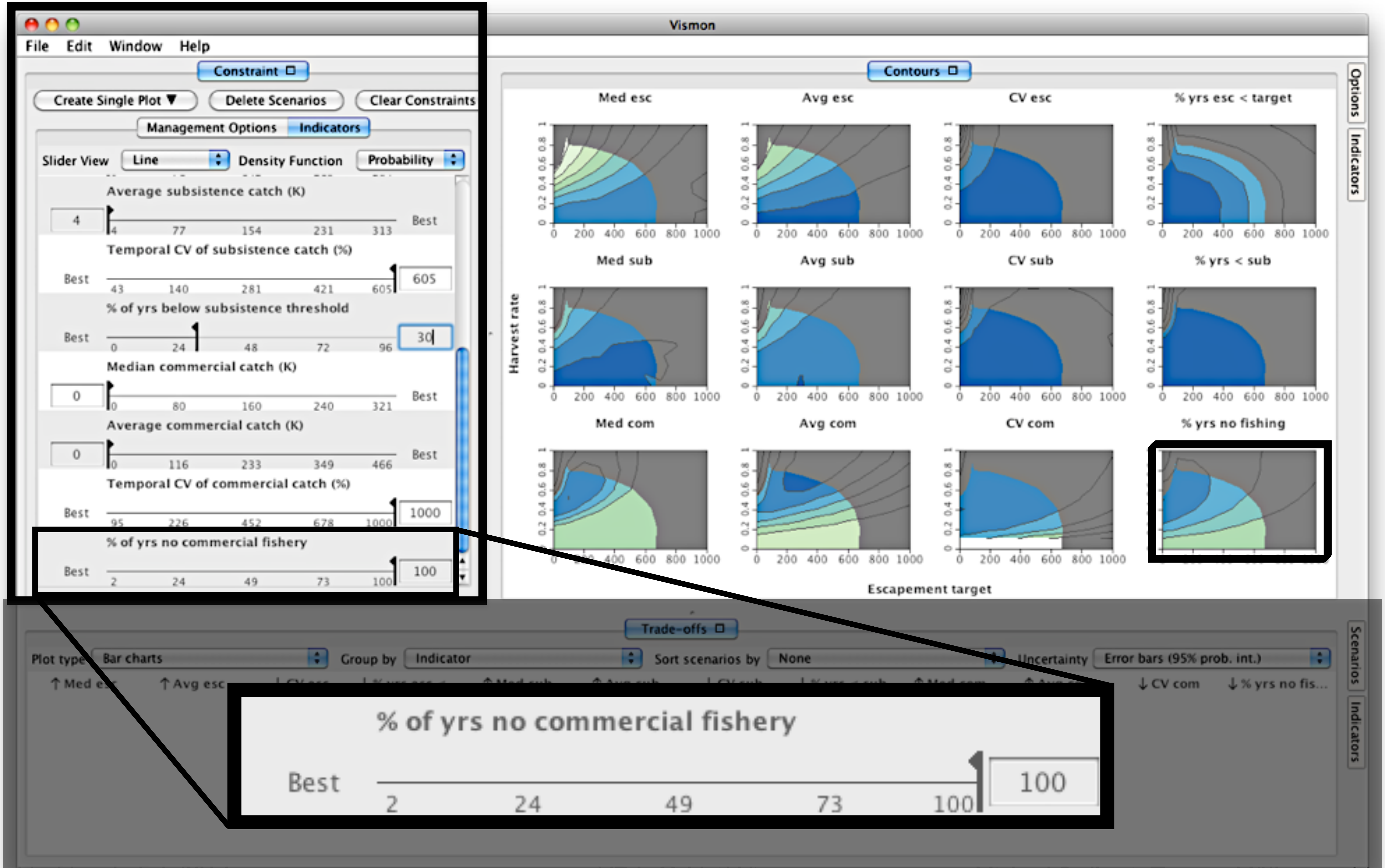

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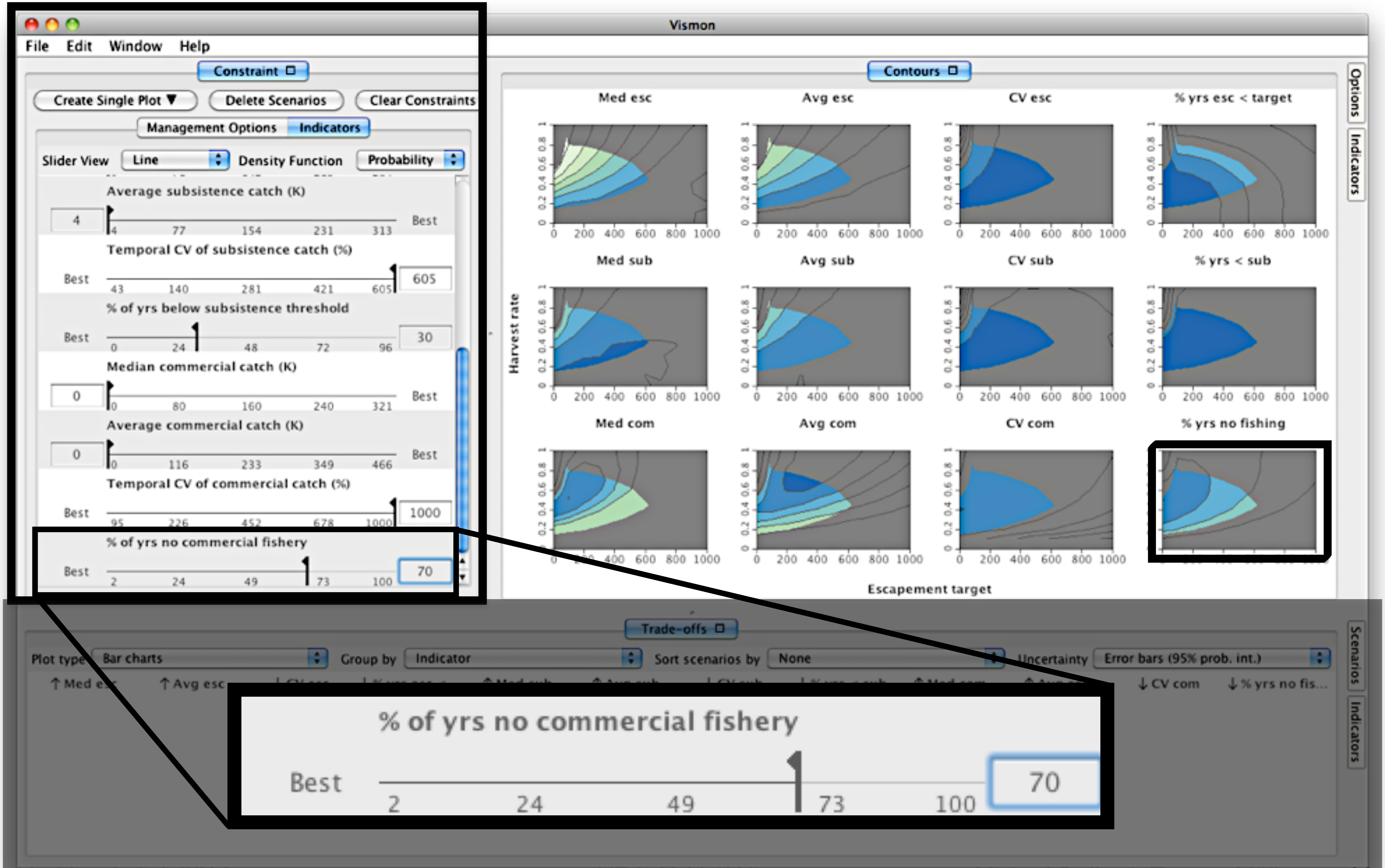

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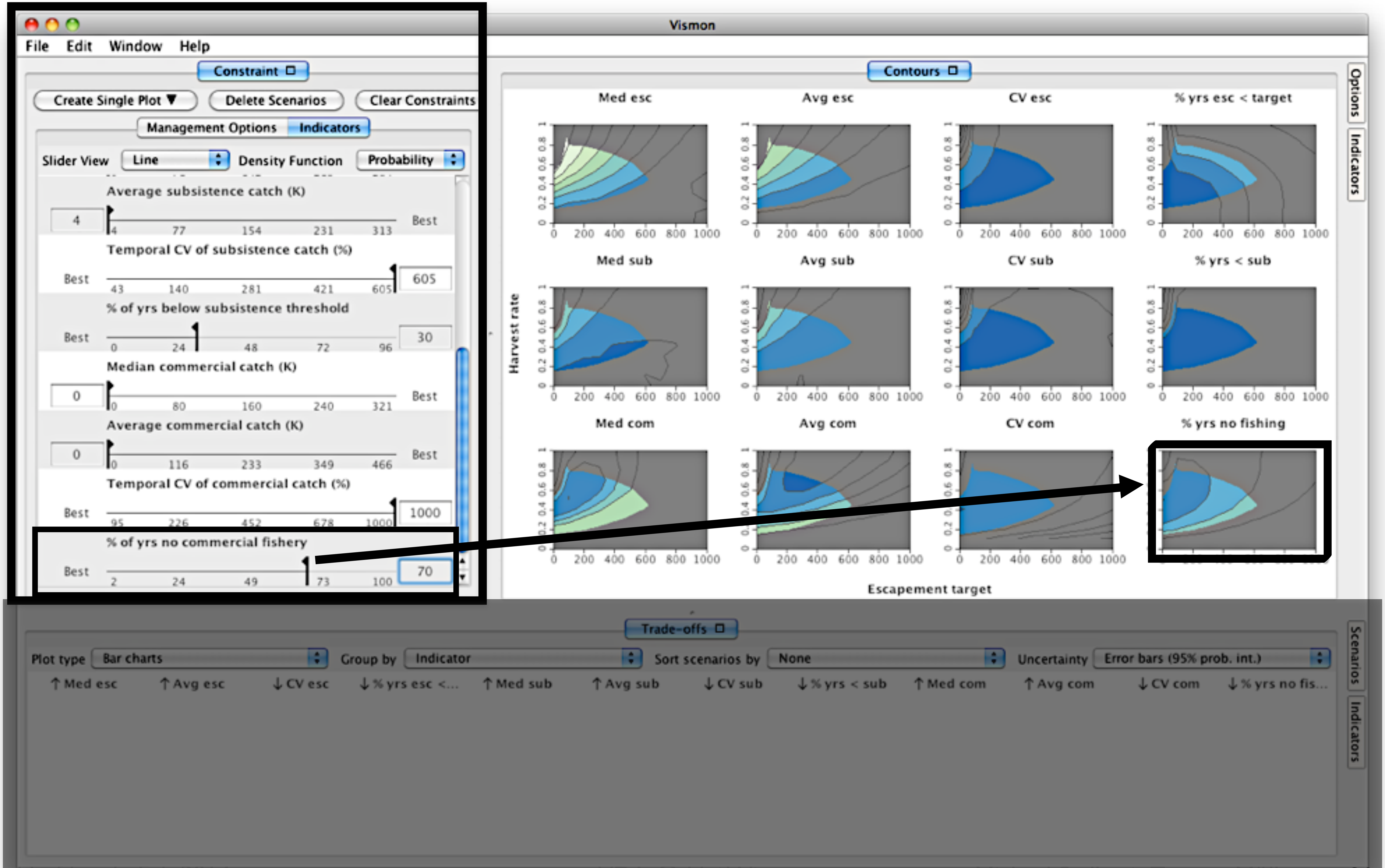

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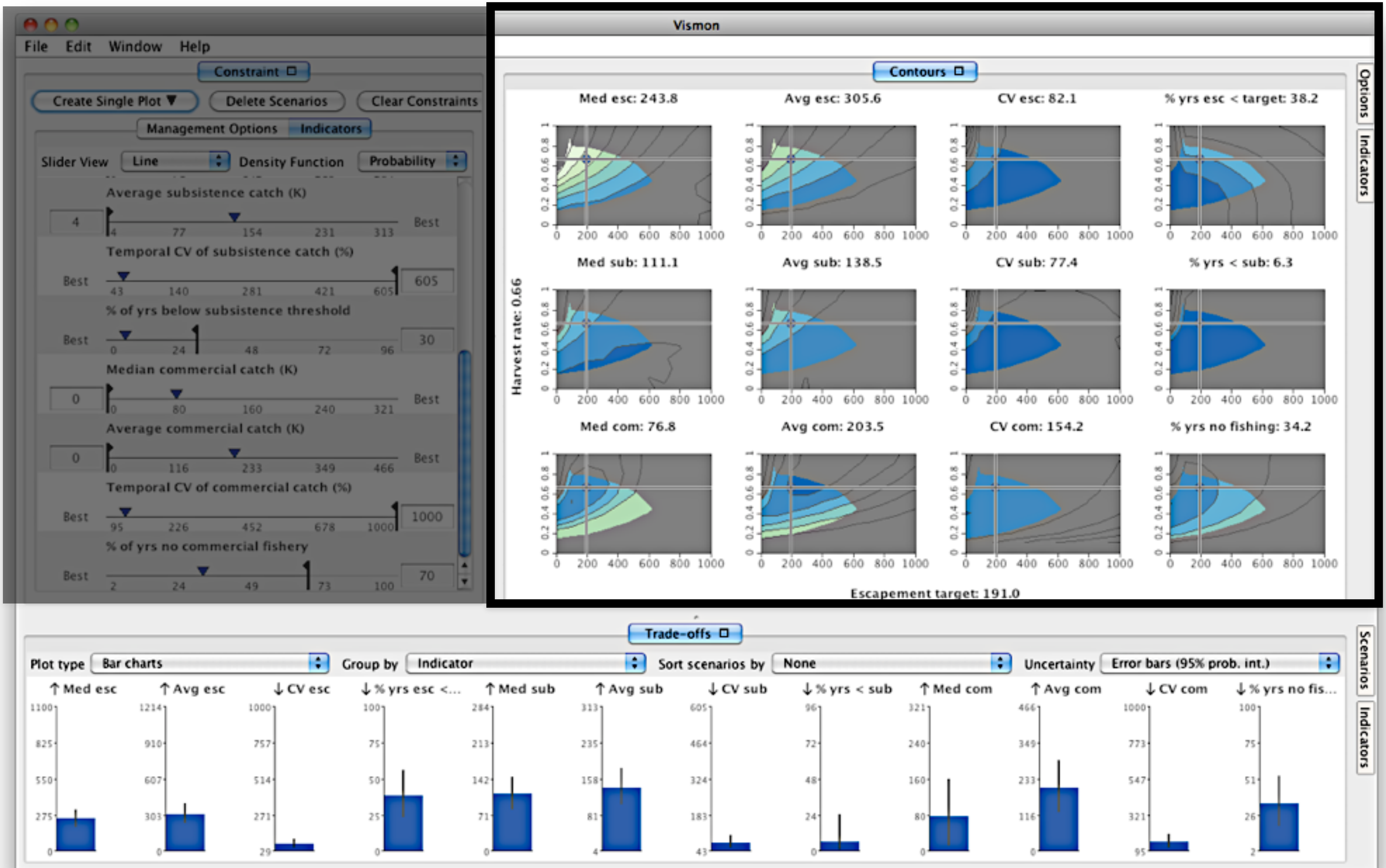
Vismon
File Edit Window Help
Constraint
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Management Options
Indicators
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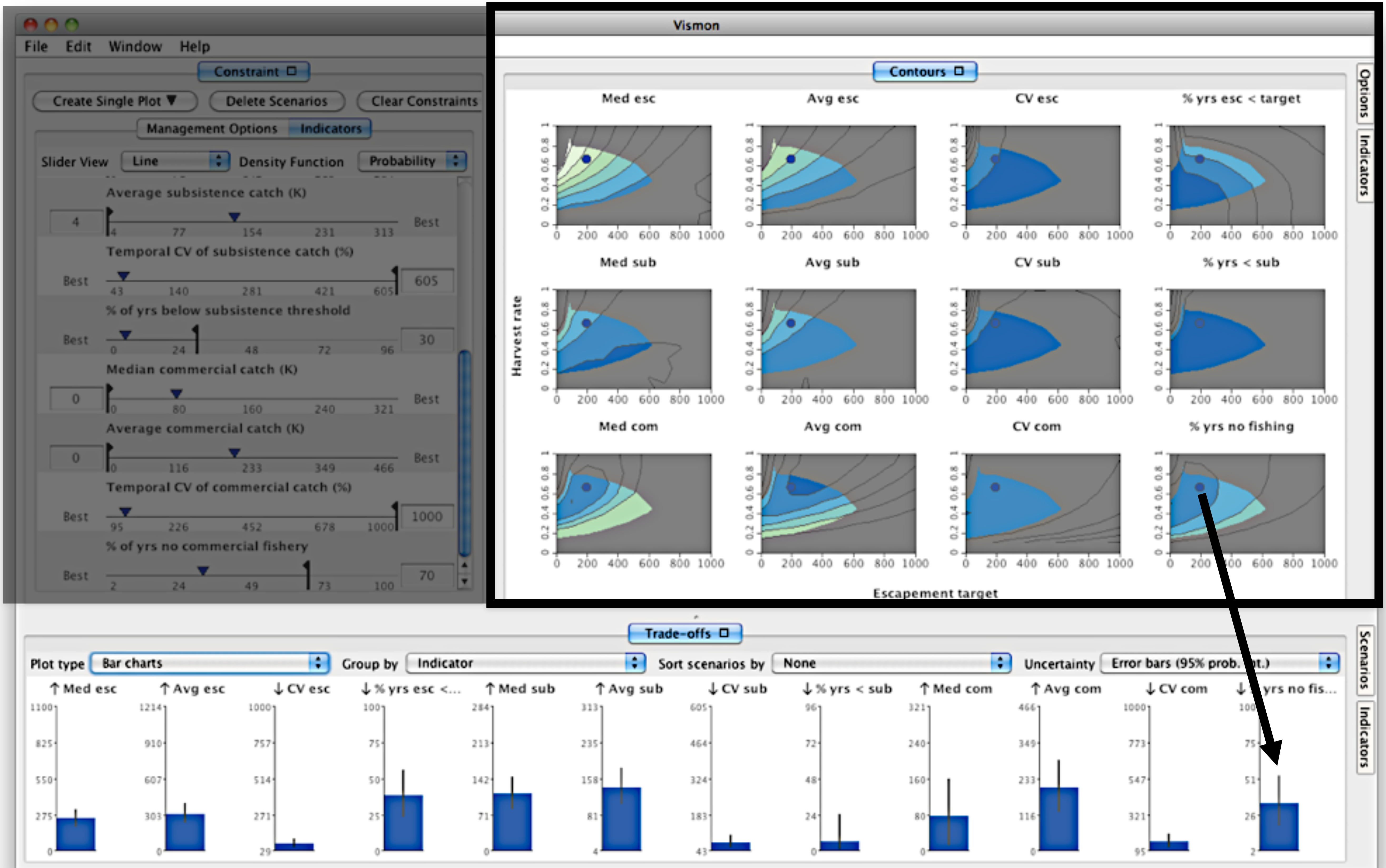
Average commercial catch (K)
Temporal CV of commercial catch (%)
% of yrs no commercial fishery
Best
Contours
Med esc: 243.8
Avg esc: 305.6
CV esc: 82.1
% yrs esc < target: 38.2
Med sub: 111.1
Avg sub: 138.5
CV sub: 77.4
% yrs < sub: 6.3
Med com: 76.8
Avg com: 203.5
CV com: 154.2
% yrs no fishing: 34.2
Harvest rate: 0.66
Escapement target: 191.0
Options
Indicators
Trade-offs
Plot type
Bar charts
Group by
Indicator
Sort scenarios by
None
Uncertainty
Error bars (95% prob. int.)
Scenarios

Selection



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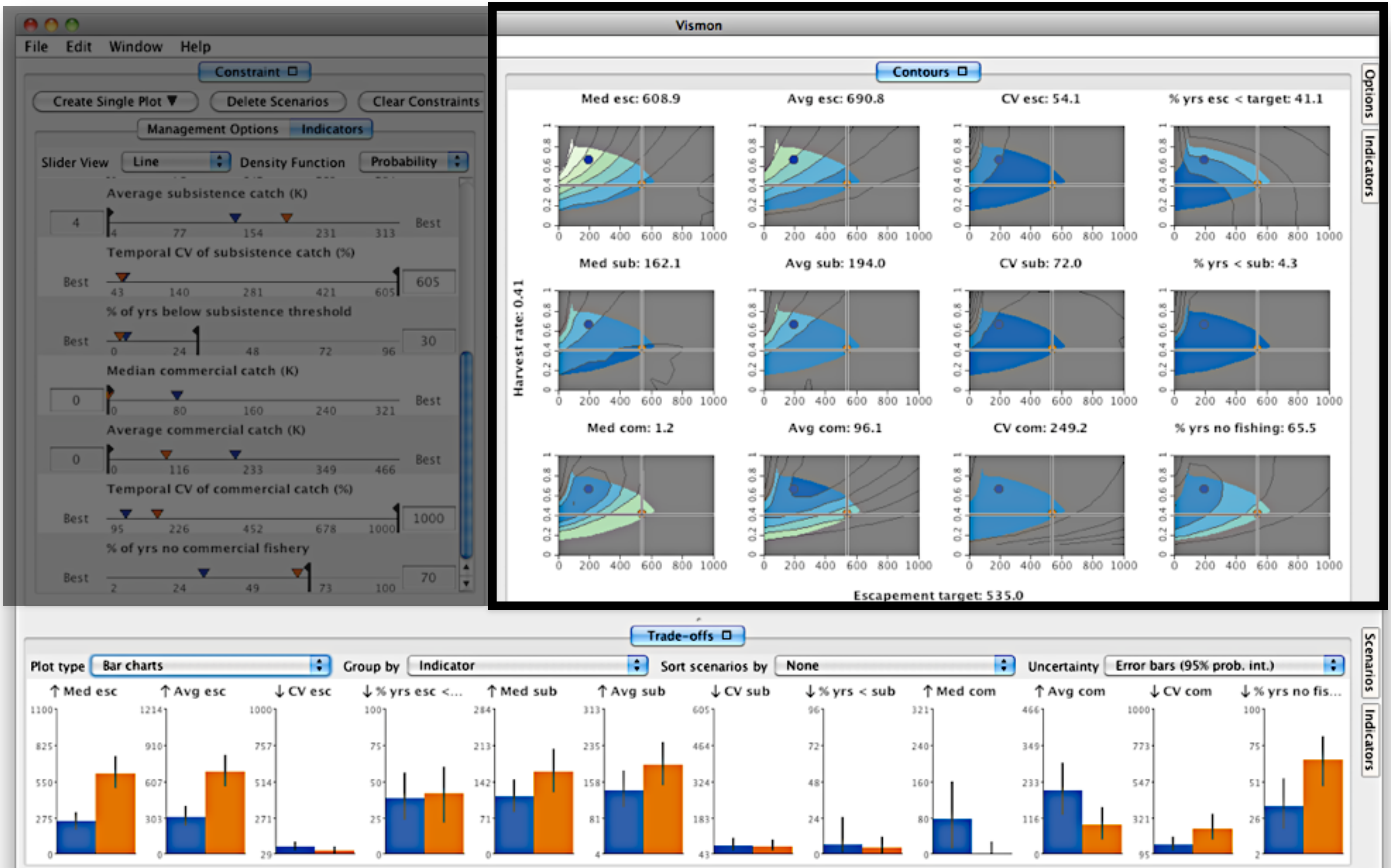
Vismon
Contours
Med esc: 608.9
Avg esc: 690.8
CV esc: 54.1
% yrs esc < target: 41.1
Med sub: 162.1
Avg sub: 194.0
CV sub: 72.0
% yrs < sub: 4.3
Med com: 1.2
Avg com: 96.1
CV com: 249.2
% yrs no fishing: 65.5
Harvest rate: 0.41
Escapement target: 535.0
File Edit Window Help
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Delete Scenarios
Clear Constraints
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Uncertainty
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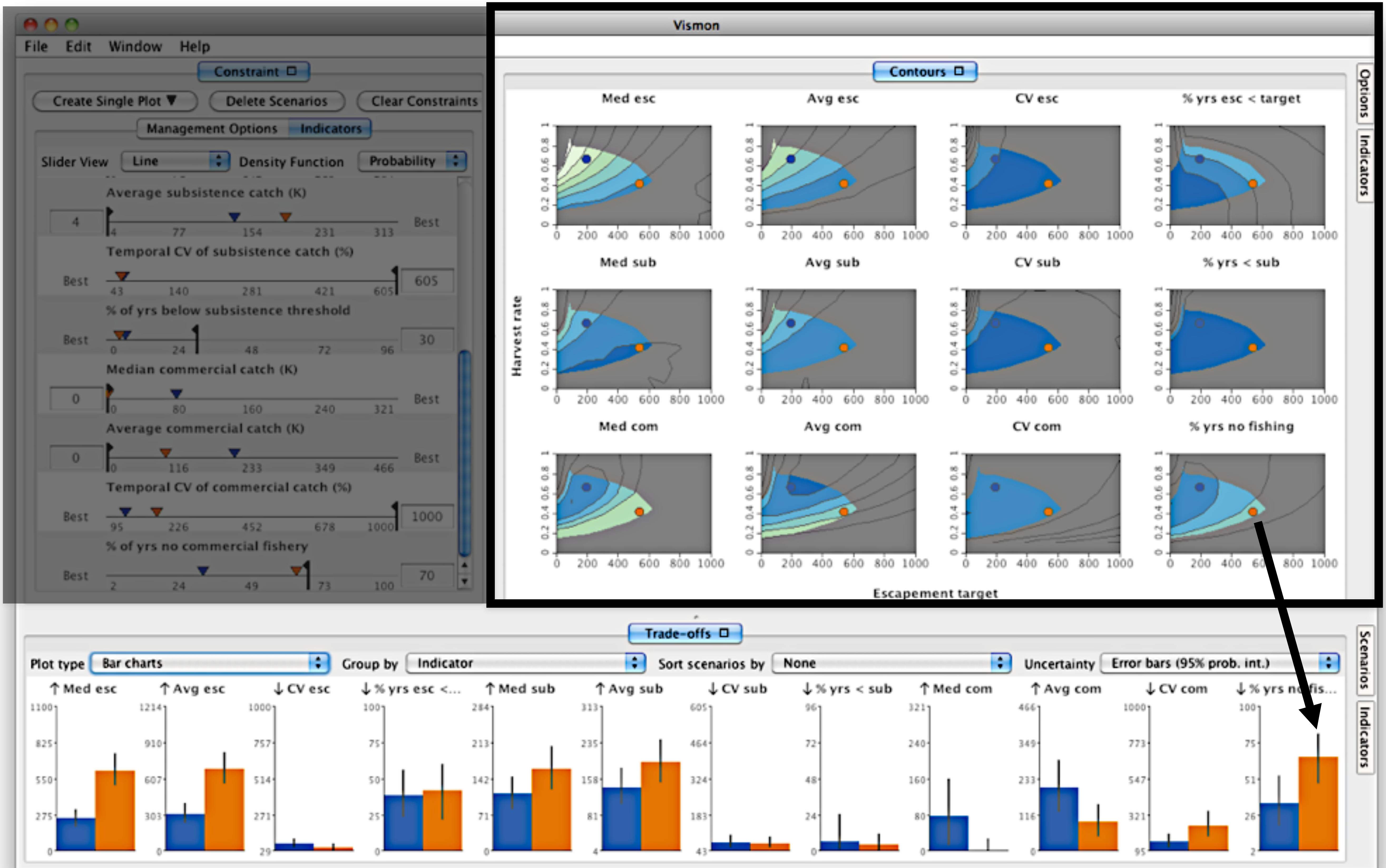
Med esc
Avg esc
CV esc
% yrs esc <...
Med sub
Avg sub
CV sub
% yrs < sub
Med com
Avg com
CV com
% yrs no fis...
Options
Indicators
Scenarios

Selection



Vismon
Contours
Med esc
Avg esc
CV esc
% yrs esc < target
Med sub
Avg sub
CV sub
% yrs < sub
Med com
Avg com
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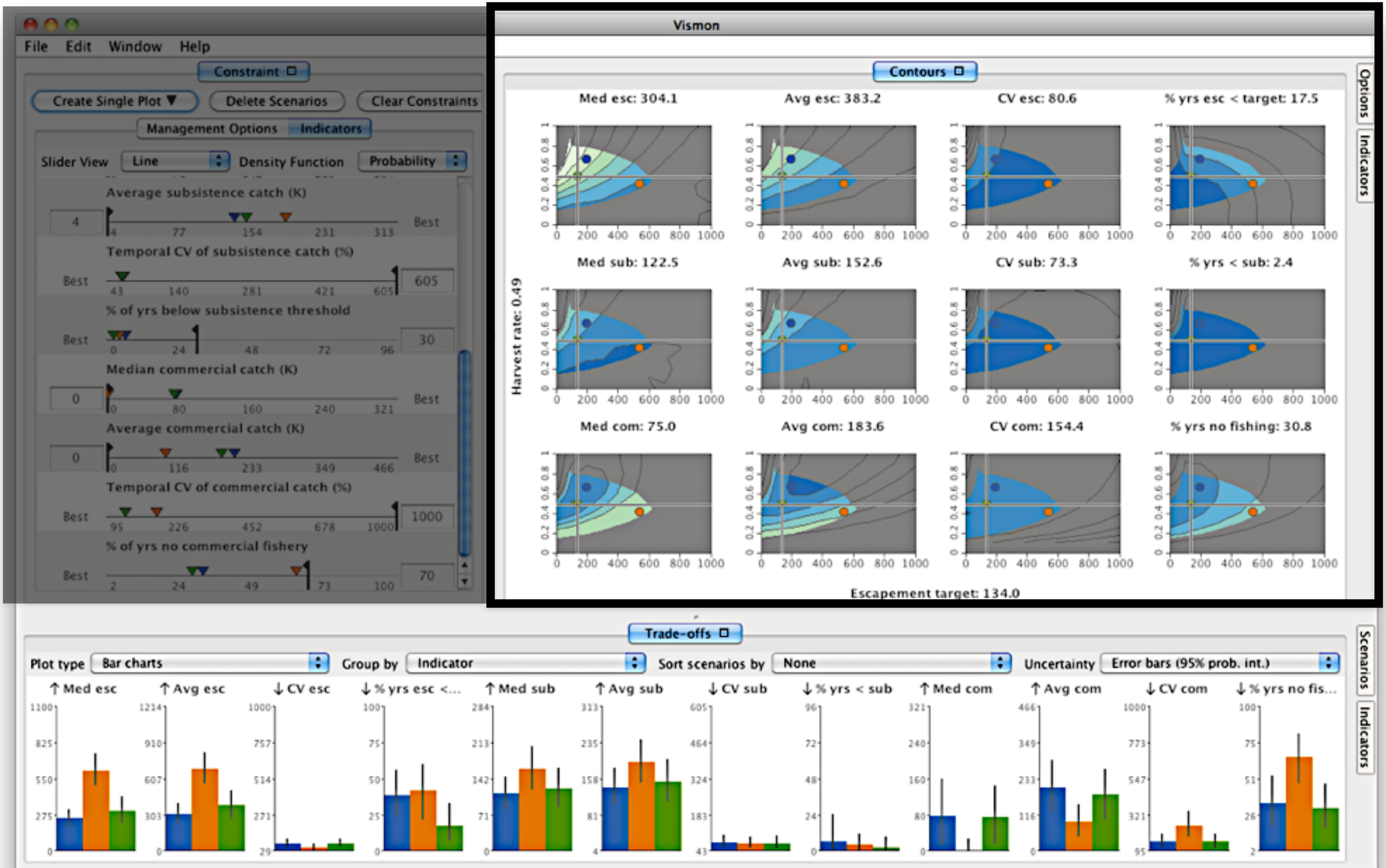

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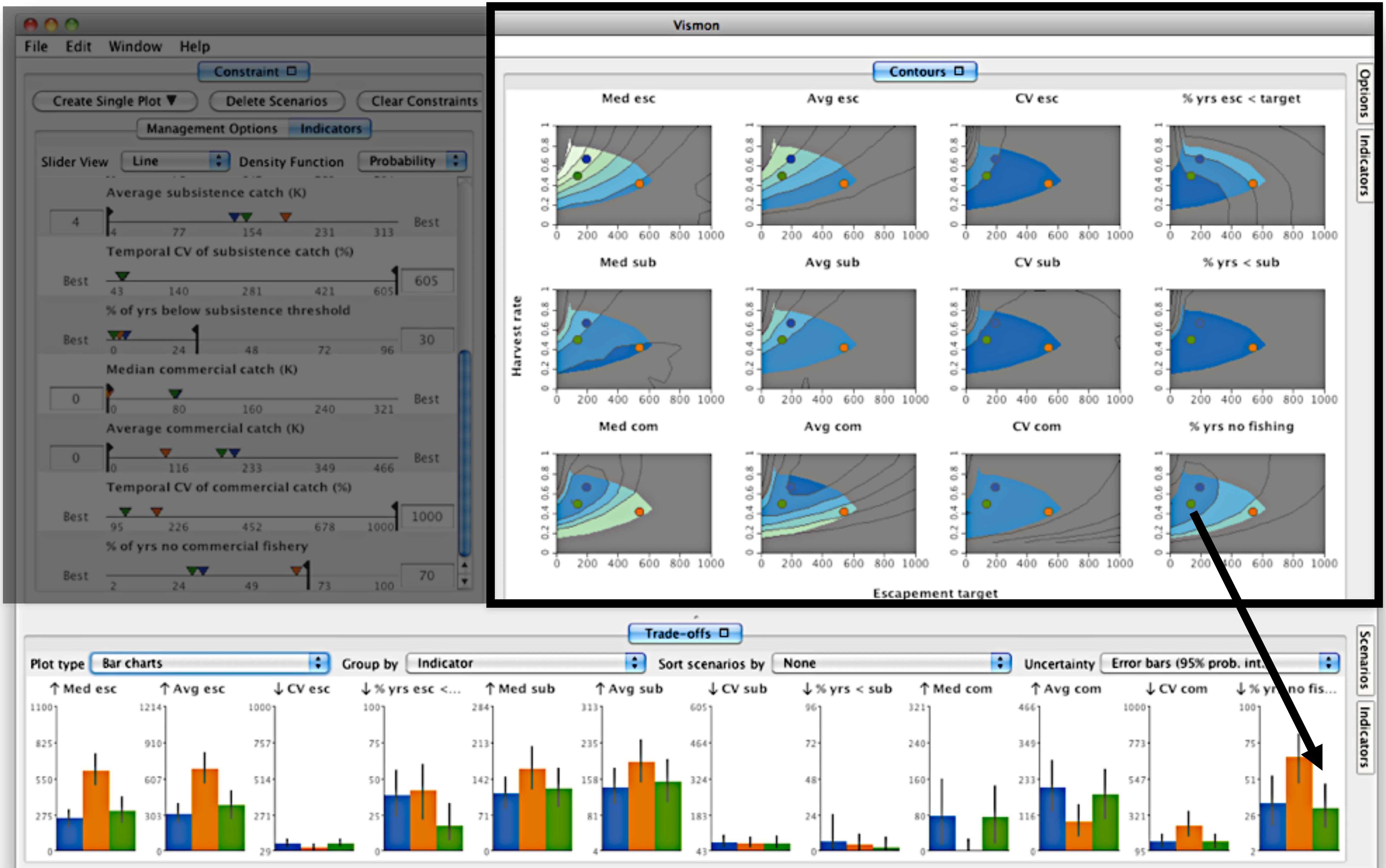
Median commercial catch (K)
Average commercial catch (K)
Temporal CV of commercial catch (%)
% of yrs no commercial fishery
Best
Vismon
Contours
Med esc: 304.1
Avg esc: 383.2
CV esc: 80.6
% yrs esc < target: 17.5
Med sub: 122.5
Avg sub: 152.6
CV sub: 73.3
% yrs < sub: 2.4
Med com: 75.0
Avg com: 183.6
CV com: 154.4
% yrs no fishing: 30.8
Harvest rate: 0.49
Escapement target: 134.0
Options
Indicators
Trade-offs
Plot type
Bar charts
Group by
Indicator
Sort scenarios by
None
Uncertainty
Error bars (95% prob. int.)
↑ Med esc
↑ Avg esc
↓ CV esc
↓ % yrs esc <...
↑ Med sub
↑ Avg sub
↓ CV sub
↓ % yrs < sub
↑ Med com
↑ Avg com
↓ CV com
↓ % yrs no fis...
Scenarios

Selection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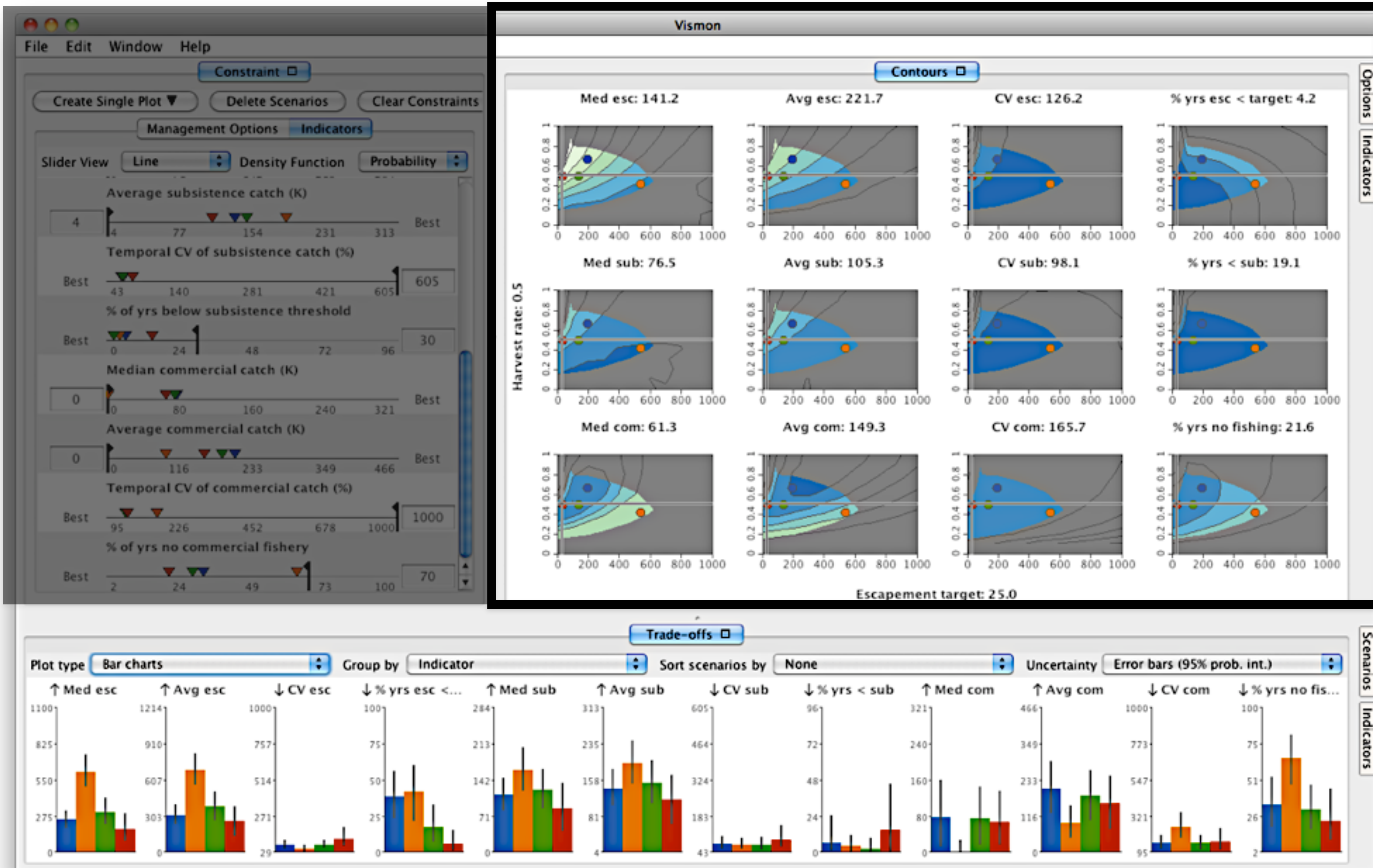
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Average commercial catch (K)
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% of yrs no commercial fishery
Vismon
Contours
Options
Indicators
Med esc: 141.2
Avg esc: 221.7
CV esc: 126.2
% yrs esc < target: 4.2
Med sub: 76.5
Avg sub: 105.3
CV sub: 98.1
% yrs < sub: 19.1
Med com: 61.3
Avg com: 149.3
CV com: 165.7
% yrs no fishing: 21.6
Harvest rate: 0.5
Escapement target: 25.0
Trade-offs
Plot type
Bar charts
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Indicator
Sort scenarios by
None
Uncertainty
Error bars (95% prob. int.)
↑ Med esc
↑ Avg esc
↓ CV esc
↓ % yrs esc <...
↑ Med sub
↑ Avg sub
↓ CV sub
↓ % yrs < sub
↑ Med com
↑ Avg com
↓ CV com
↓ % yrs no fis...
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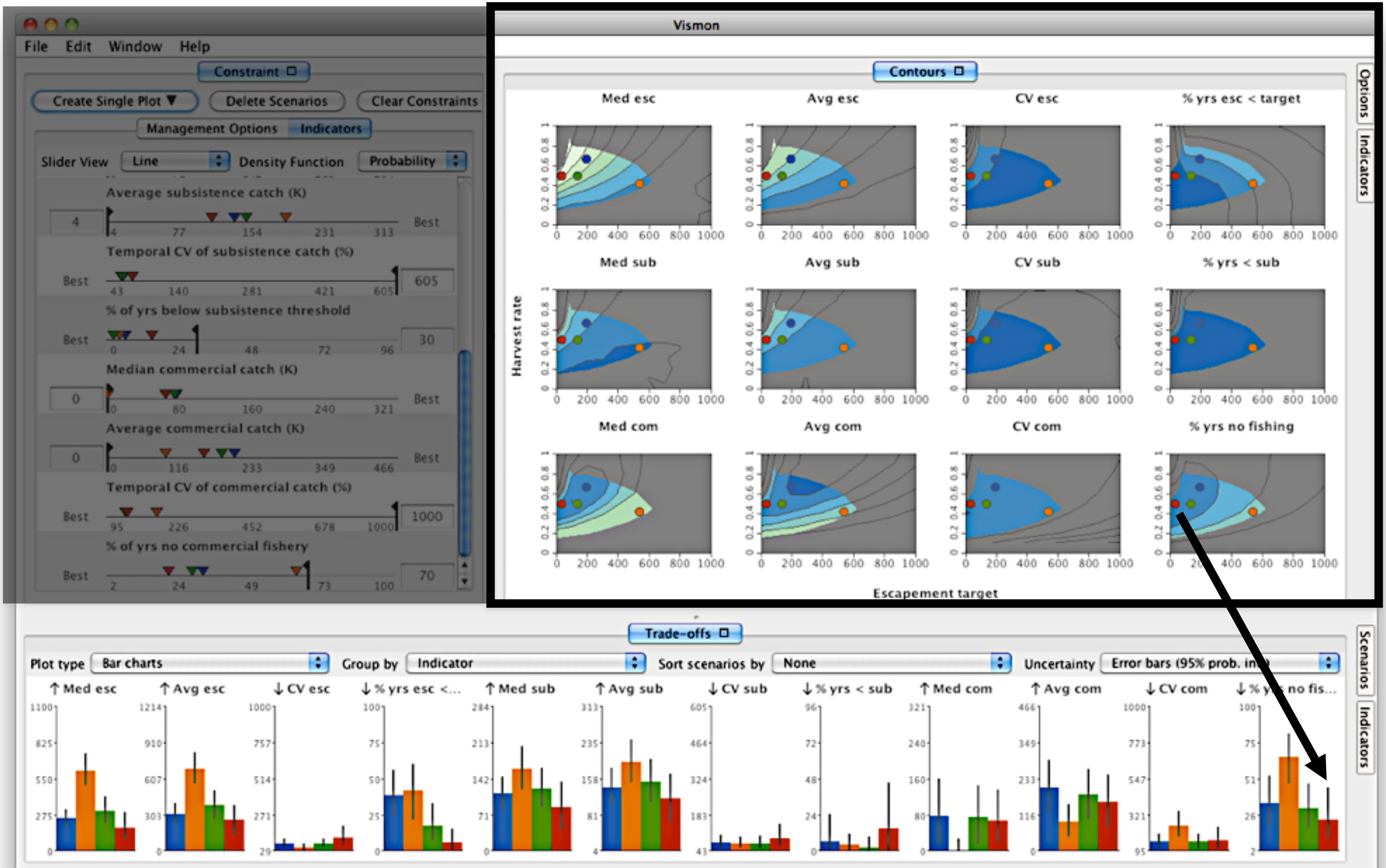

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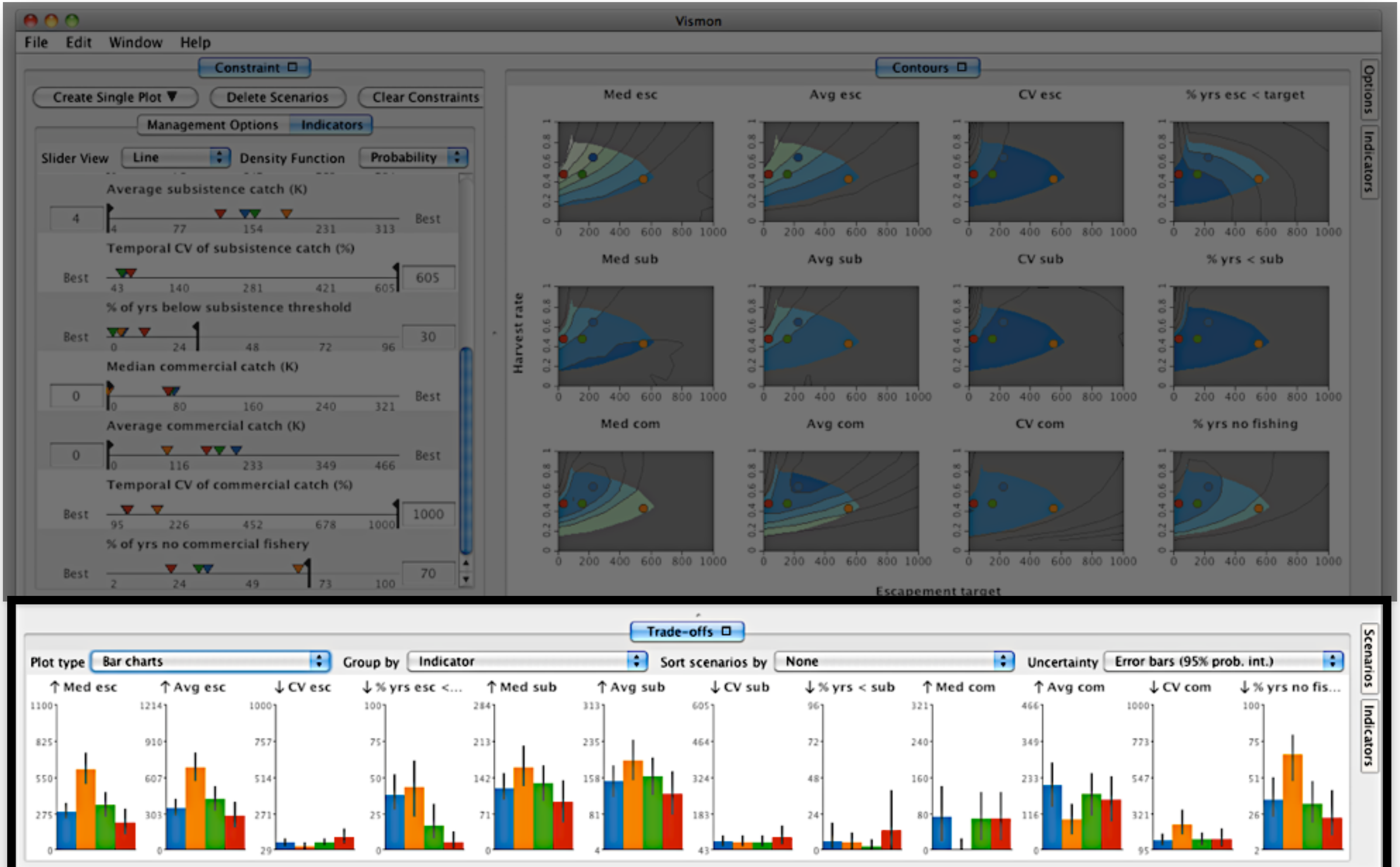
Trade-off quantification

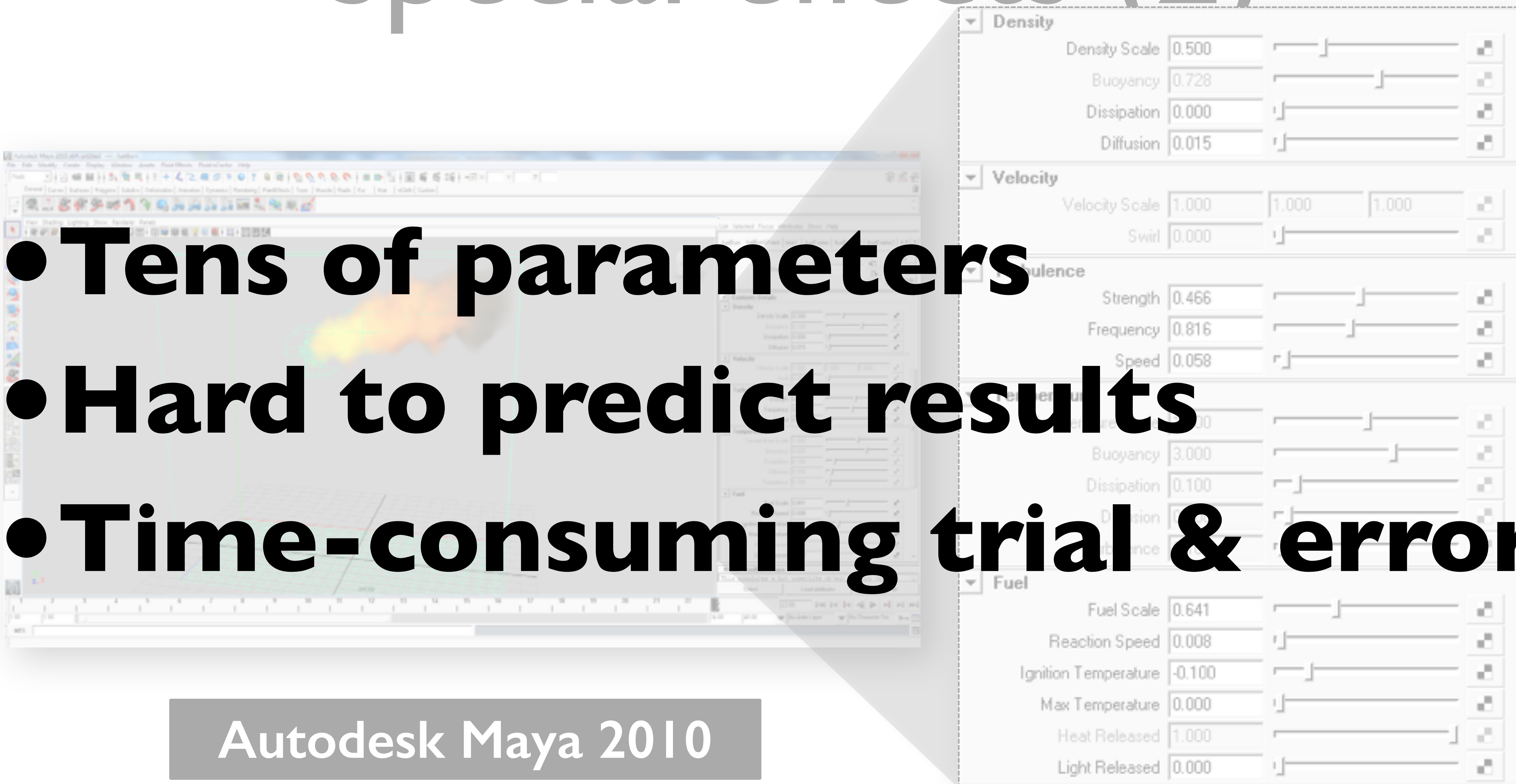


FluidExplorer
Fluid animation

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)



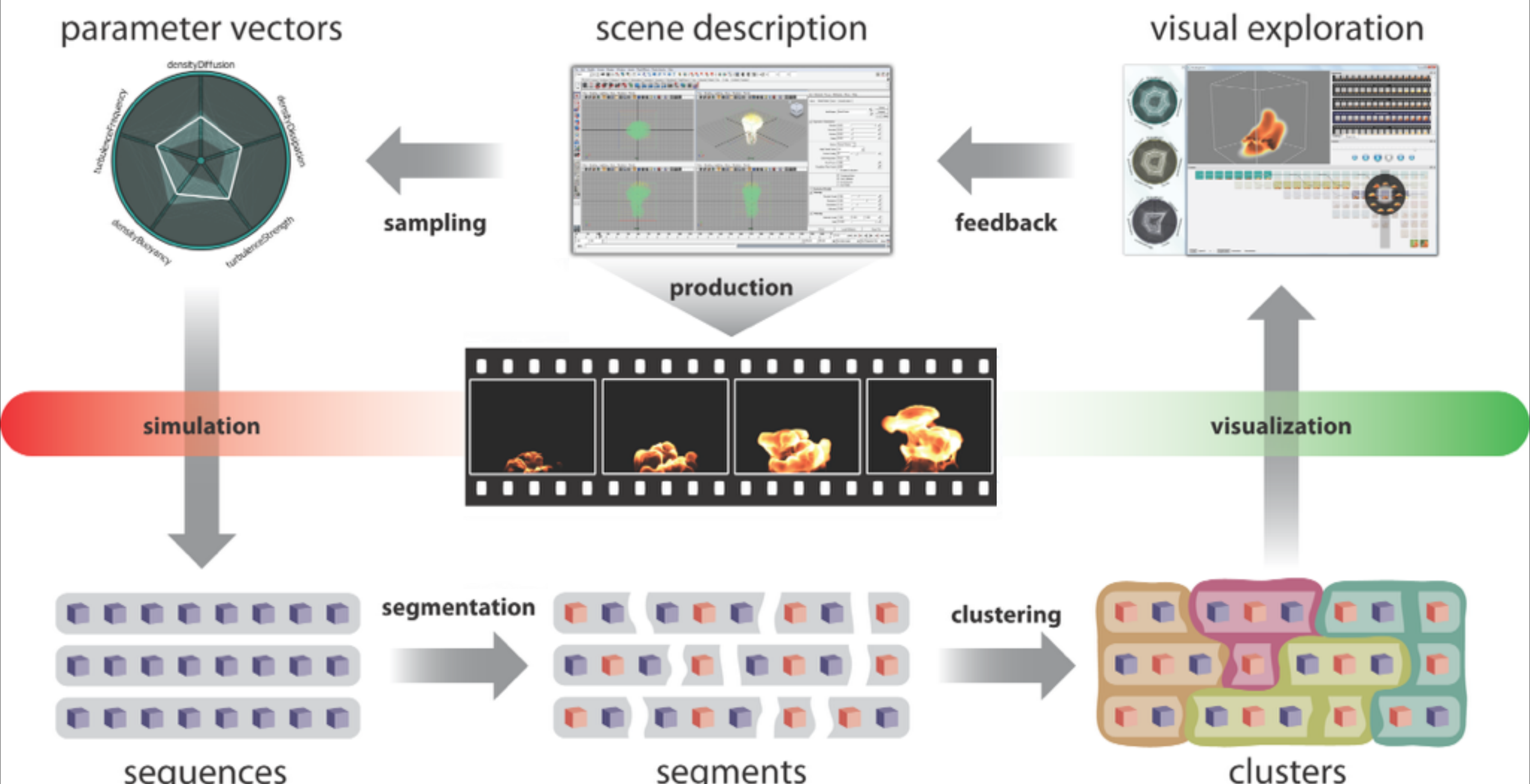
- **Tens of parameters**
- **Hard to predict results**
- **Time-consuming trial & error**

Autodesk Maya 2010

The Zen of tuning parameters!

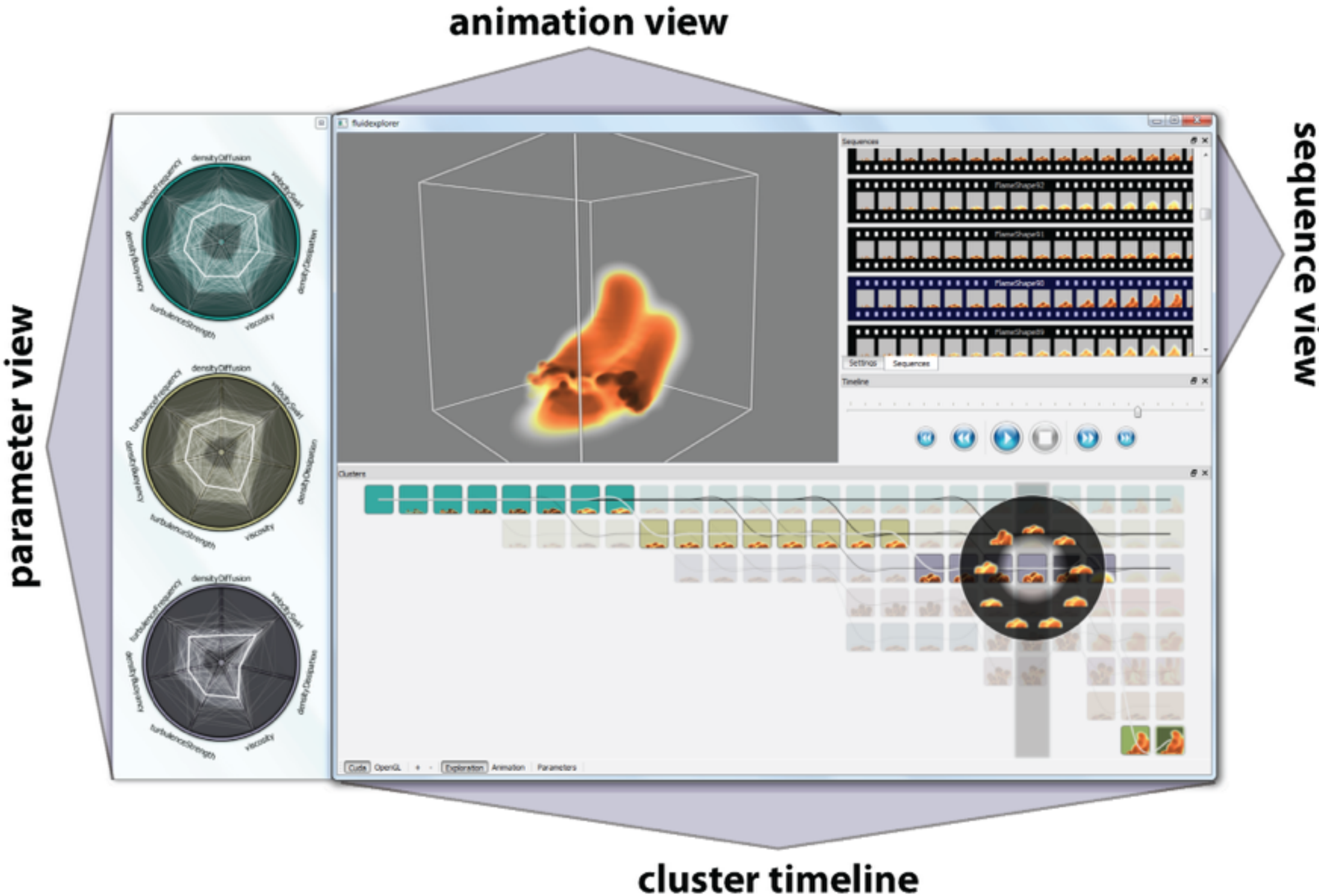
- very tedious and time consuming
- loop over
  - guess a parameter combination
  - wait for animation result (often minutes)
  - evaluate result (often visually)
- did we reach a stable parameter region?

Overview



parameter vectors
densityDiffusion
densityDissipation
turbulenceStrength
densityBuoyancy
turbulenceFrequency
scene description
visual exploration
sampling
feedback
production
simulation
visualization
segmentation
clustering
sequences
segments
clusters

Visualization



Evaluation

- iterative loop -- human-centered design
- Vismon: 4 years
- FluidExplorer: 1 year

Overview

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  - Problem abstraction
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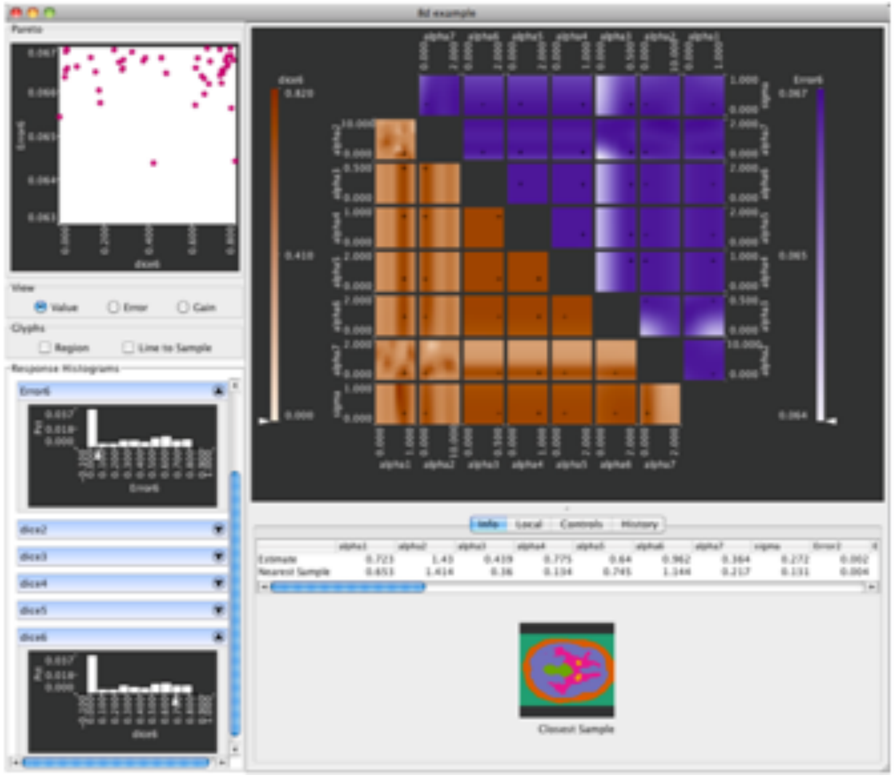
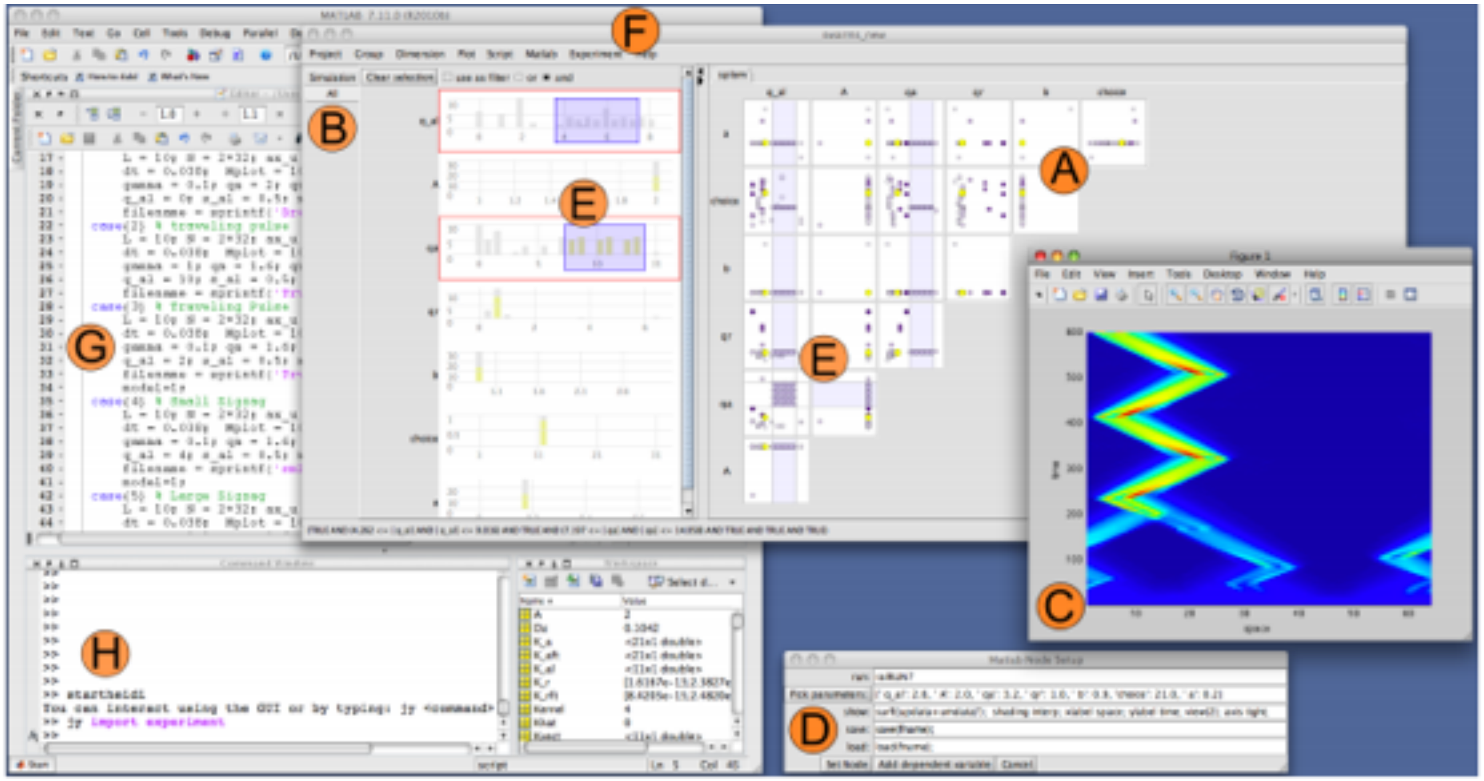
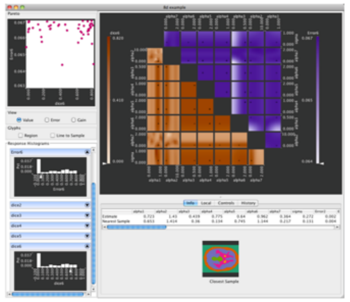
  - Strategies
- Challenges



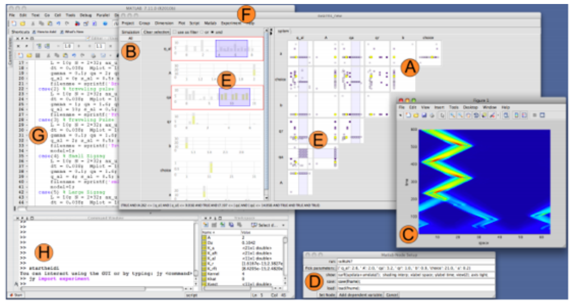
Tuner
[Torsney-Weir et al., Vis 2011]



Paraglide
[Bergner et al., TVCG 2013]

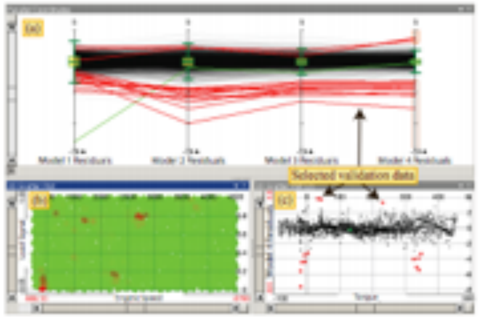


Tuner
[Torsney-Weir et al., Vis 2011]

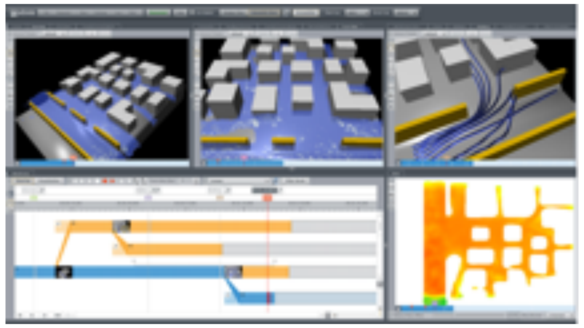


Paraglide
[Bergner et al., TVCG 2013]

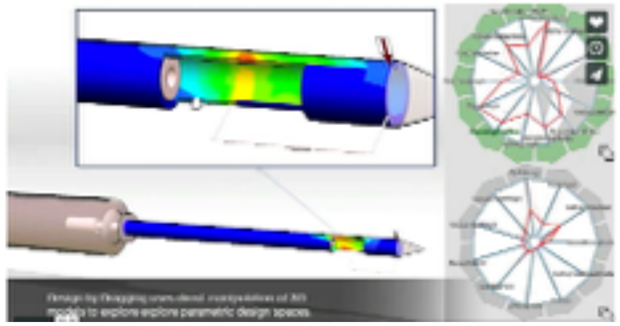
Paramorama
[Pretorius et al., InfoVis 2011]



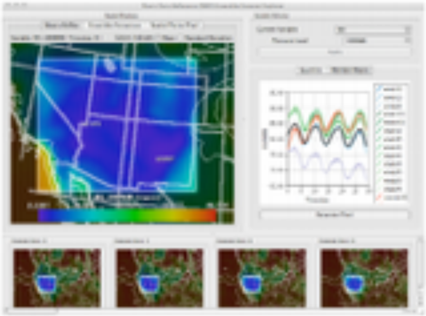
HyperMoVal
[Piringer et al., EuroVis 2010]



World Lines
[Waser et al., Vis 2010]



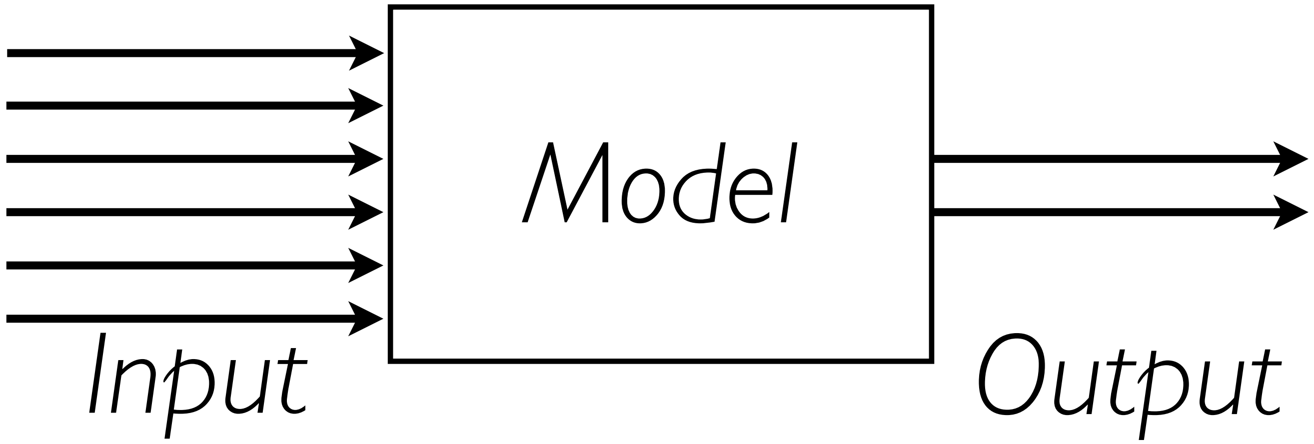
Design by Dragging
[Coffey et al., SciVis 2013]

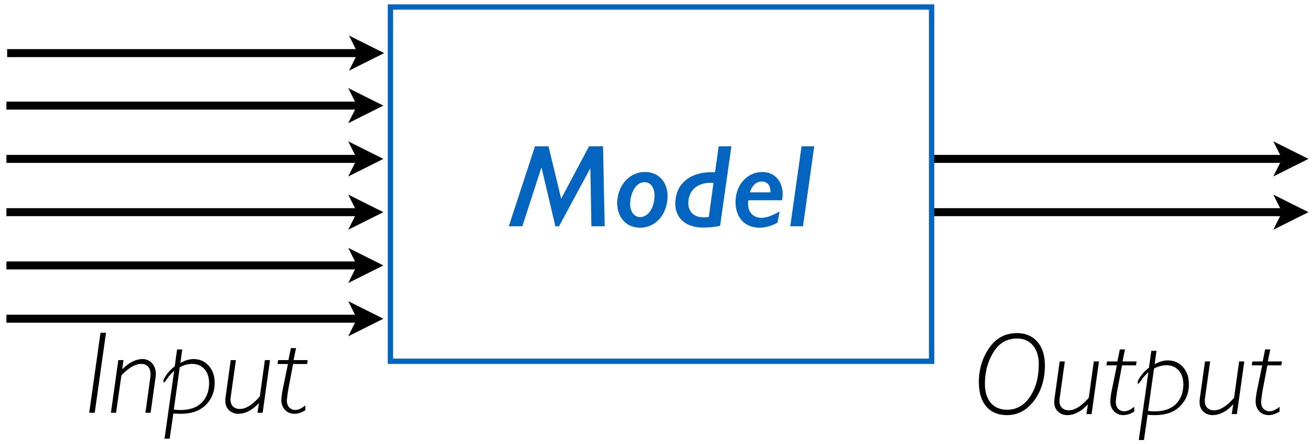


Ensemble-Vis
[Potter et al., 2009]

… and many more

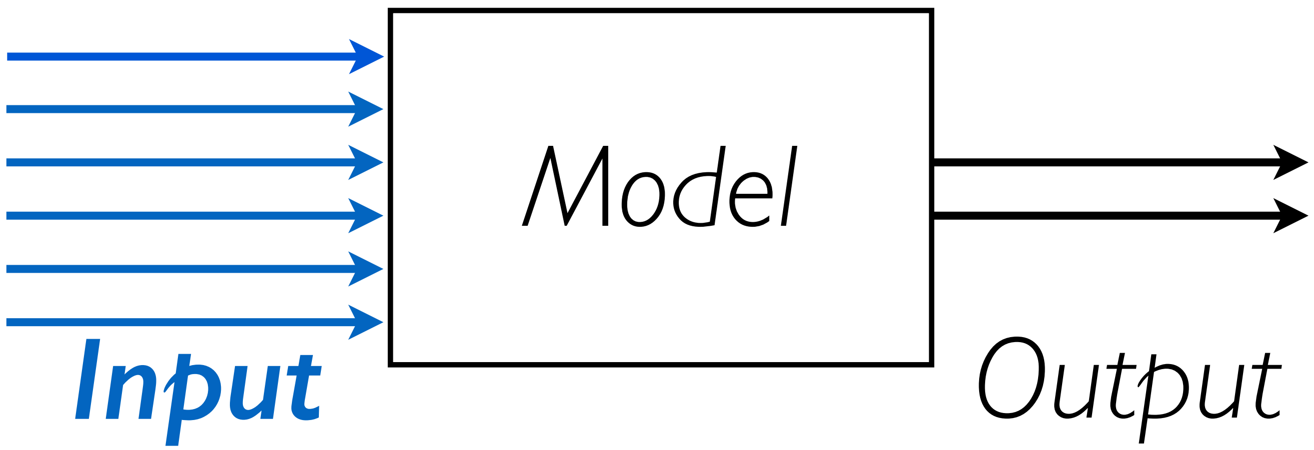
Problem Abstraction


Model
Input
Output



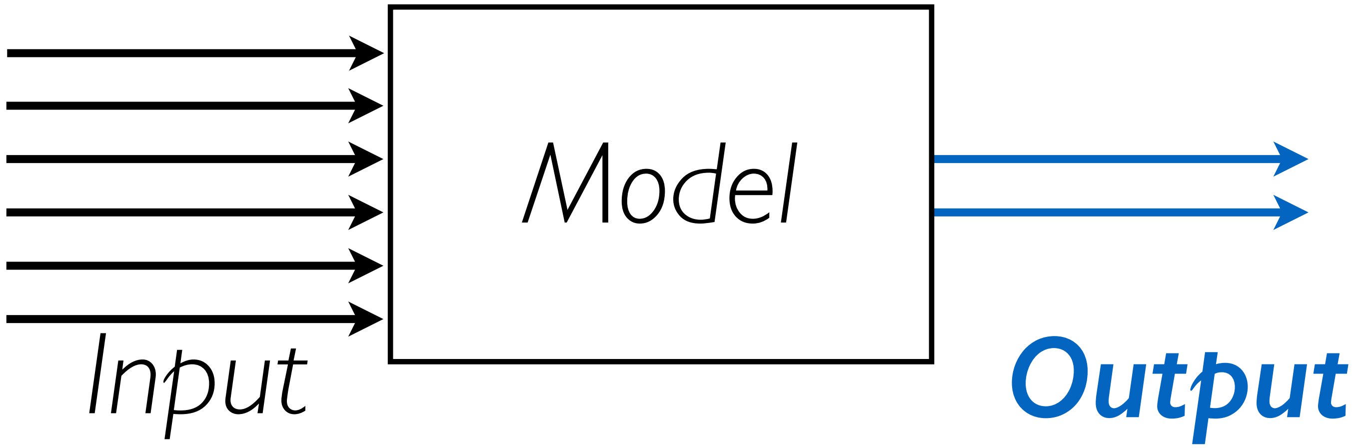
Model

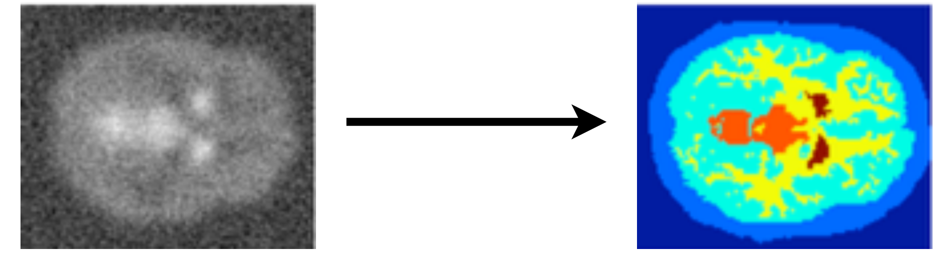
- simulation model, prediction model, …
- … but also algorithm
- stochastic, deterministic
- usually black box (to us as Vis researchers)



Inputs

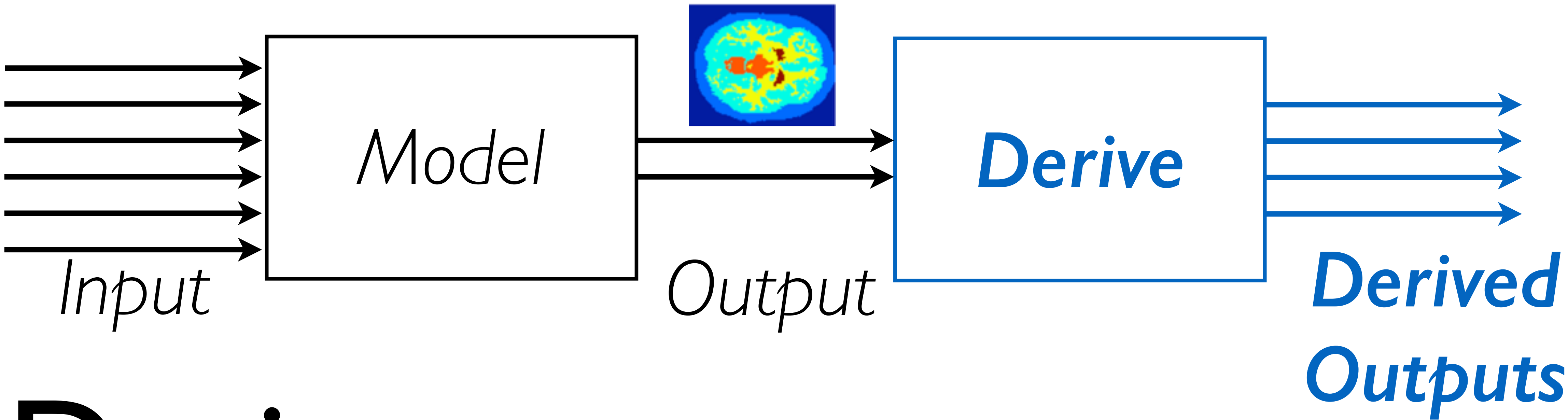
- well chosen by the scientist, i.e. people care about their inputs
- normally continuous (quantitative data)
  - need to sample the space
- categorical data common too (e.g. use of a different algorithm)






Outputs

- typically complex objects, e.g.
  - 2D, 3D images (Tuner)
  - animations (FluidExplorer)
  - performance graphs (fuel cells)
- hard to evaluate / compare many complex outputs



Derive

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

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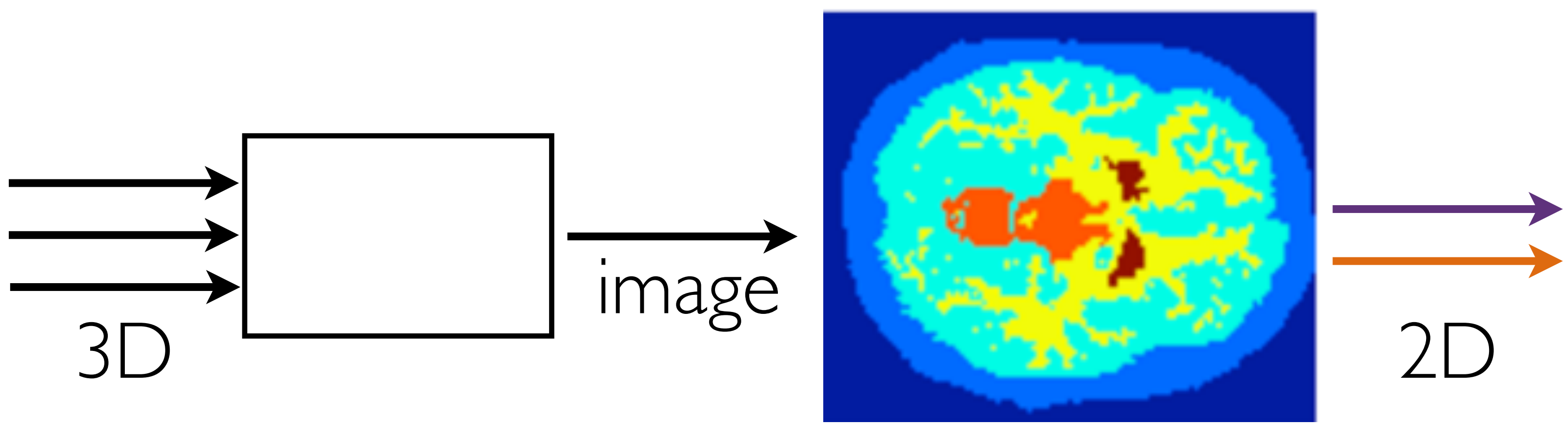
Optimization

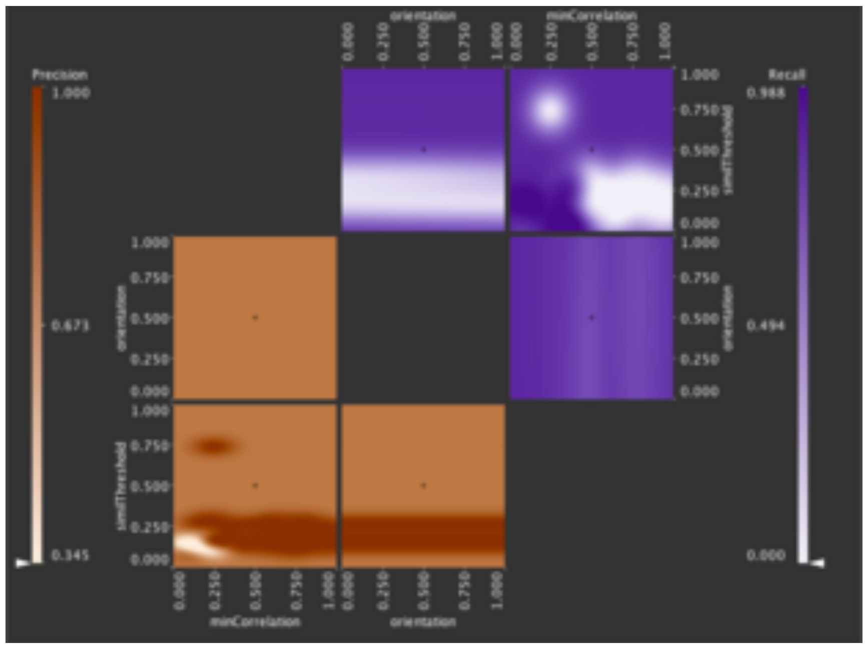
"Find the 'best' parameter combination."

- subjective optimization

“Find the ‘best’ parameter combination.”

- subjective optimization
- derive objective measures

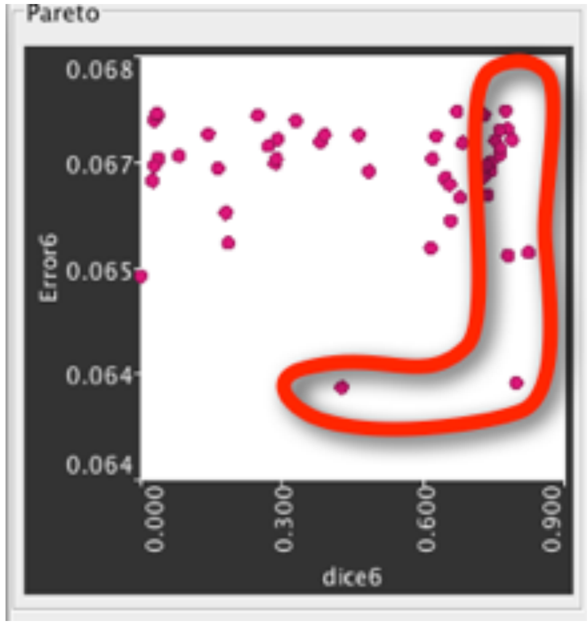




Tuner
[Torsney-Weir et al., Vis 2011]

"Find the 'best' parameter combination."

- subjective optimization
- derive objective measures
- often times multiple objectives that need to be balanced
  - one: no Vis, just use some optimization toolbox
  - two: 2D Pareto front (e.g. Tuner) →
  - multiple: facilitate multi-objective trade-off (e.g. Vismon)

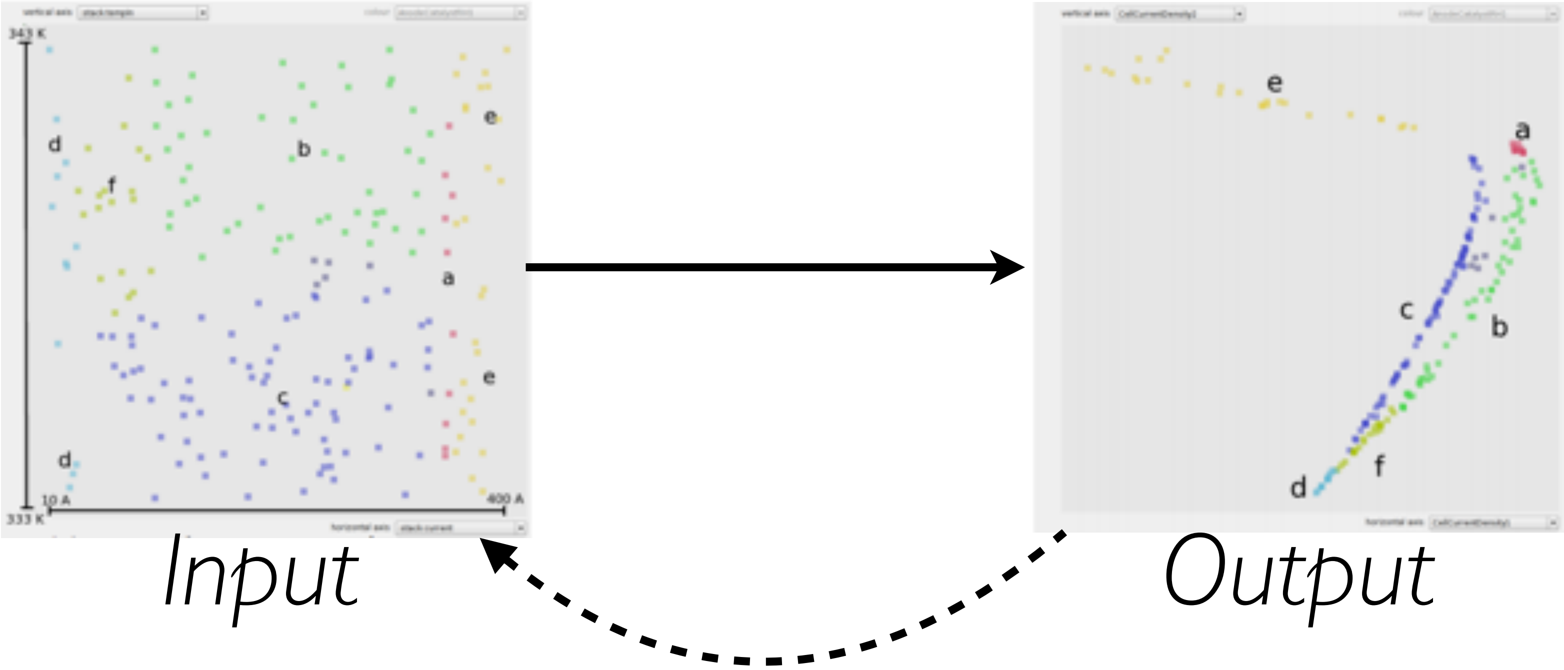


Tuner

Partitioning

"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



Paraglide
[Bergner et al., TVCG 2013]

Fitting

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

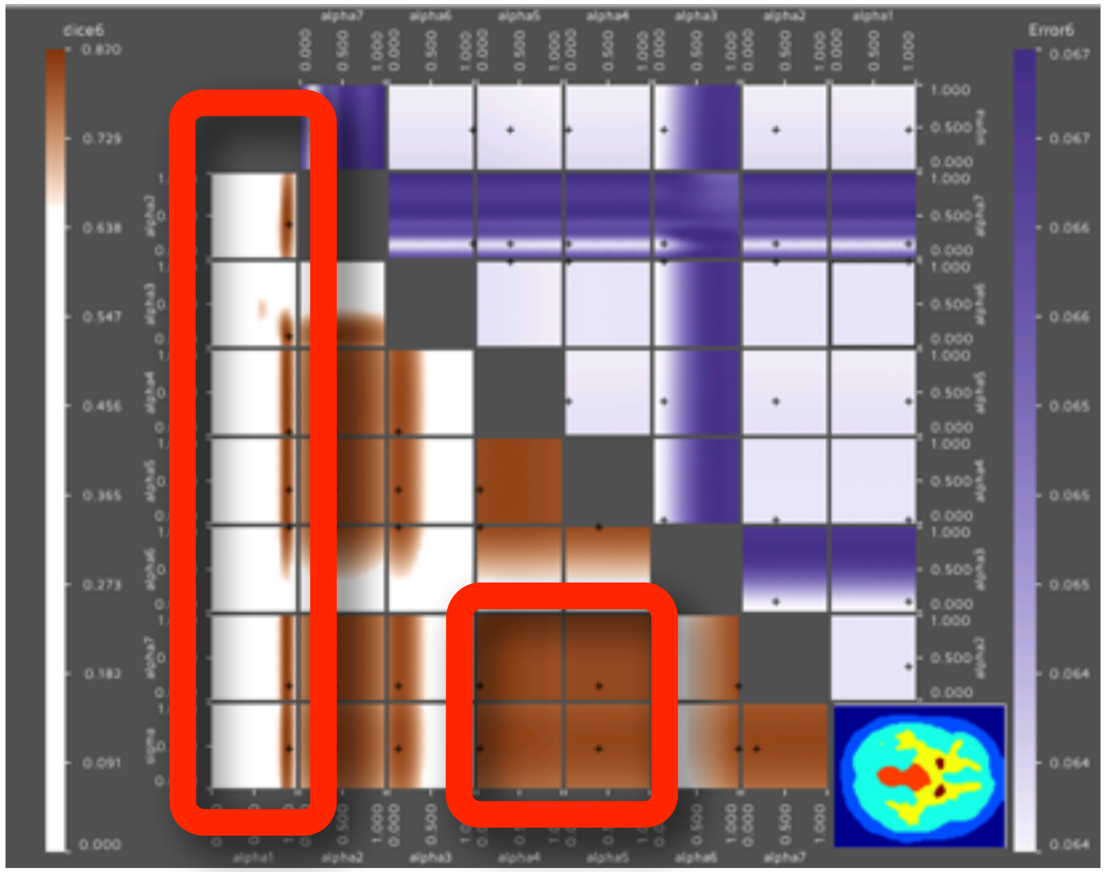
- Data fitting - given real inputs and their outputs, improve the understanding / modeling
- Inverse Problem (level sets) - given ONLY the outputs, what inputs would yield this behavior?
- could be formulated as an optimization problem
- e.g. HyperMoVal [Piringer et al., EuroVis 2010]

Sensitivity

“What ranges/variations of outputs to expect with changes of input?”

"What ranges/variations of outputs to expect with changes of input?"

- <u>Optimization</u> - *"How stable are my optimal parameter settings?"*



Tuner

"What ranges/variations of outputs to expect with changes of input?"

- <u>Optimization</u> - *"How stable are my optimal parameter settings?"*

- <u>Partitioning</u> - *"How quick/slow are the transition from one behavior to another?"*

- <u>Fitting</u> - *"How close does the simulation come to the actual measured data?"*

Uncertainty

- structural uncertainty (model vs. real system)—"*How much might the model differ from reality?*"

- aleatoric/statistical uncertainty (of stochastic models)—"*How much do (non-deterministic) runs with the same parameter settings differ?*"

- interpolation uncertainty (of surrogate models)—"*How accurate are interpolations between sampled runs?*"

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Main strategies

- Trial and error (traditional approach)

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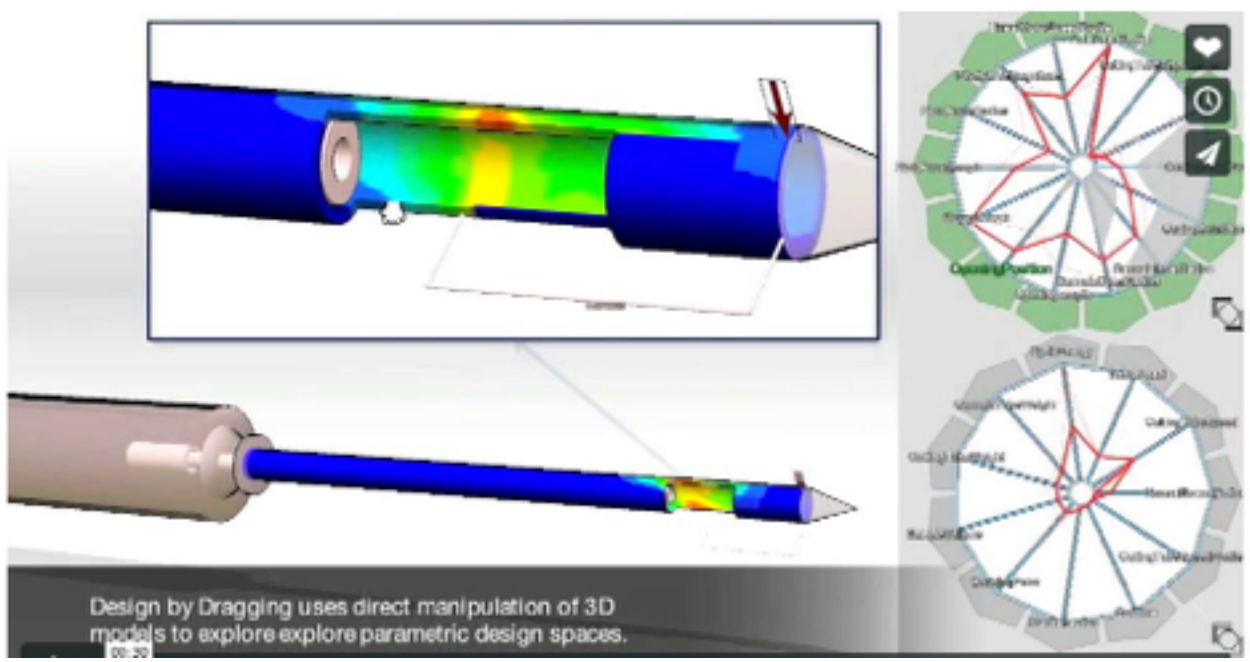
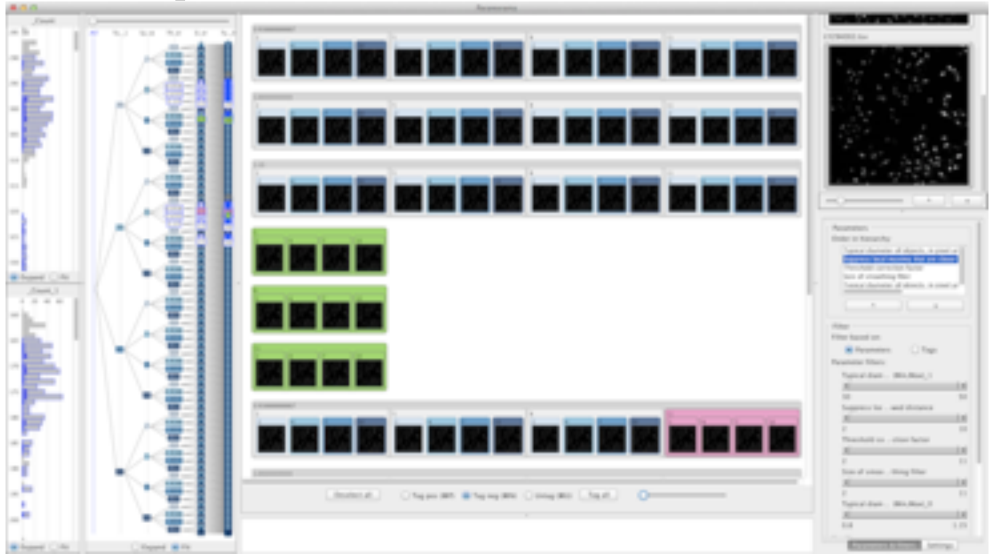
- Local —> global tweaking



Design by Dragging
[Coffey et al., SciVis 2013]

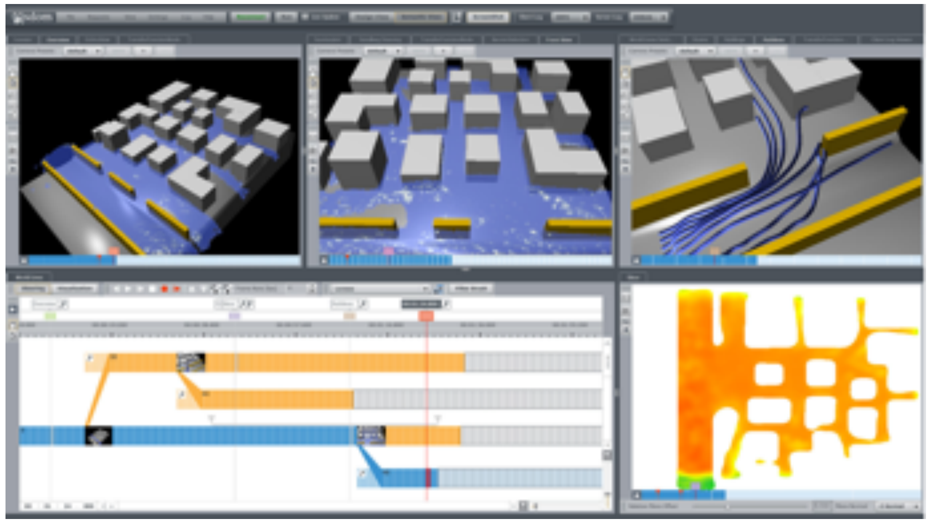
Main strategies

- Trial and error (traditional approach)
- Local —> global tweaking
- Global —> local exploration
  - FluidExplorer, Vismon, Tuner
  - many others: Paramorama [Pretorius et al., InfoVis 2011]



Main strategies

- Trial and error (traditional approach)
- Local —> global tweaking
- Global —> local exploration
- Steering
  - simulation steering: e.g. real-time simulators
  - computational steering: e.g. change the grid size, stop if no insight



World Lines
[Waser et al., Vis 2010]

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Technical Challenges

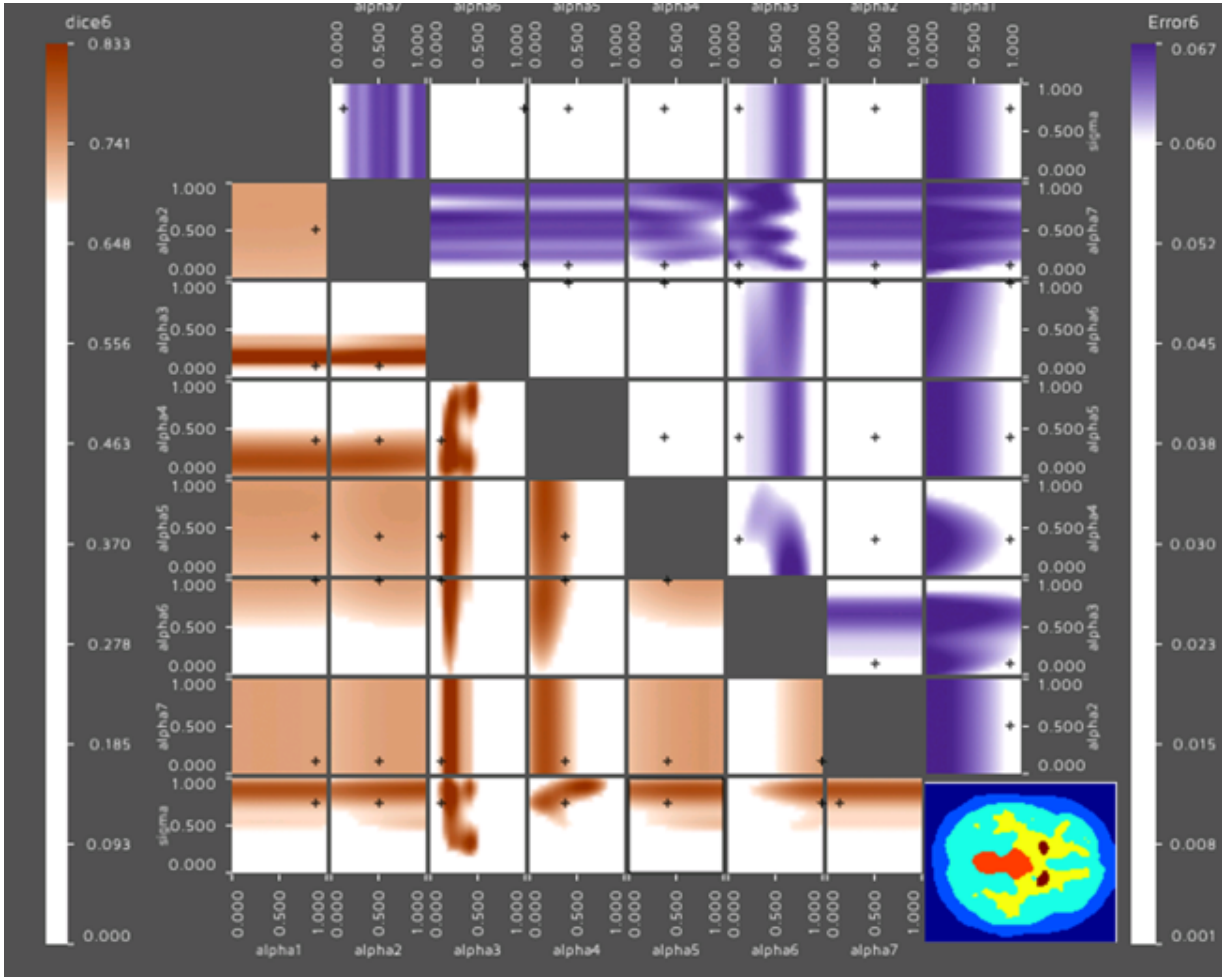
Data Management

- messy real data (“Big Data”)
  - uncertainty
  - data wrangling
- large data sets
  - from real data
  - from simulations
  - storage (“exascale computing”)
  - out-of-core

Sampling

- trading-off time and accuracy
  - 1h / sim — 24 sims / day
  - 1s / sim — 86,400 sims / day
- time — would like to have analysis result in less than a day (there always is a cost / deadline!)
- accuracy - would like to have as dense a sampling as possible
- often reconstruct / infer values at non-sampled values from sampled neighbors (surrogate model)

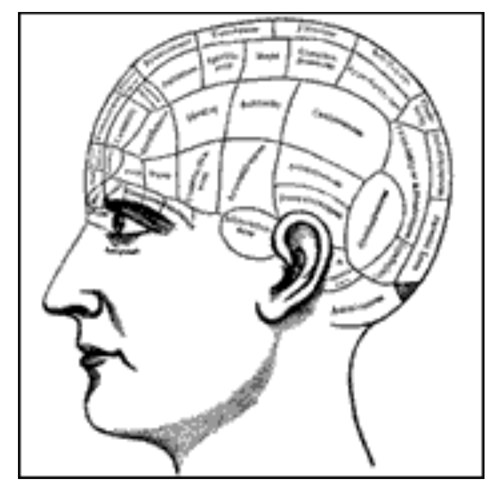
Real-time Rendering



Cognition and Design Challenges

Cognition

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

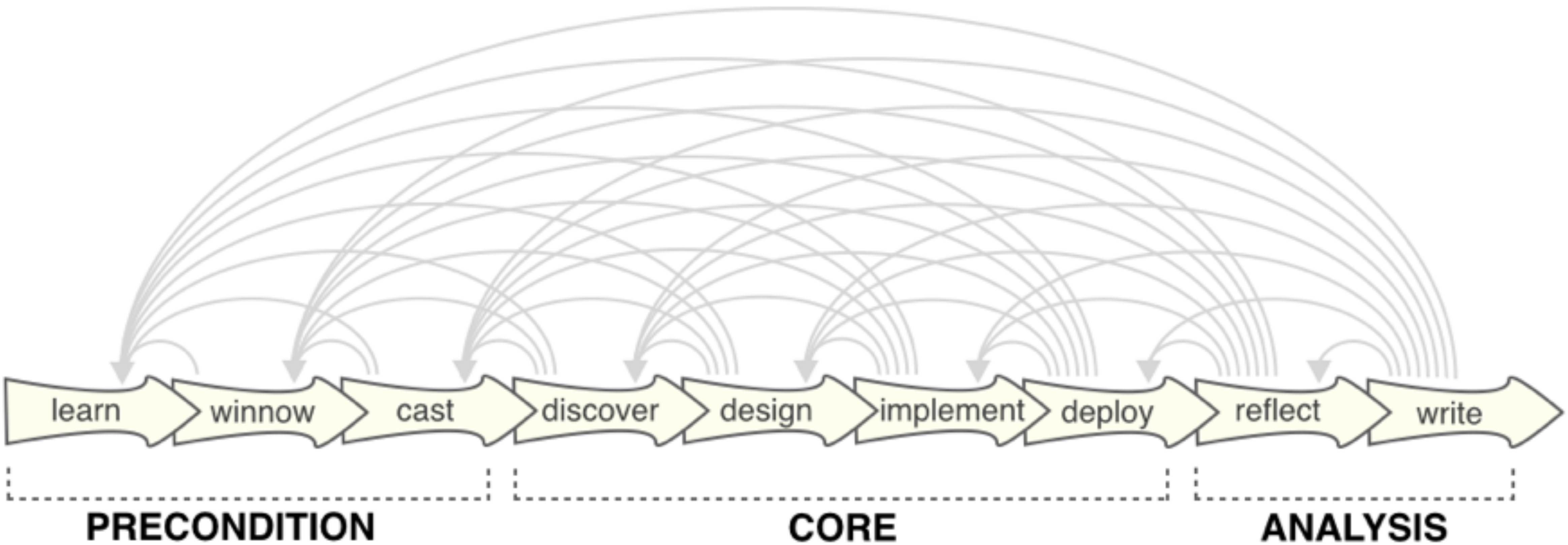


Visual + Interaction Design

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

Process Challenges

Design Studies



Design Study Methodology
[Sedlmair et al., InfoVis 2012]

From Design Studies to Theory

- From single design/case studies to more generalizable insights?

From Design Studies to Theory

"the visualization and data analysis cookbook"

abstract data & task

↓

data analysis technique

From Design Studies to Theory

- work-in-progress, together with

Christoph Heinzl
FH Wels

Harald Piringer
VRVis

Stefan Bruckner
Univ. of Bergen

Edi Gröller
TU Vienna

Summary

- understanding parameter space - an essential task of computational science
- visual tools—universal across domains / stimulate intuition about complex (in-out) relationships
- recognition—*"This reduced the work of days to a couple of hours."*

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BC INNOVATION COUNCIL

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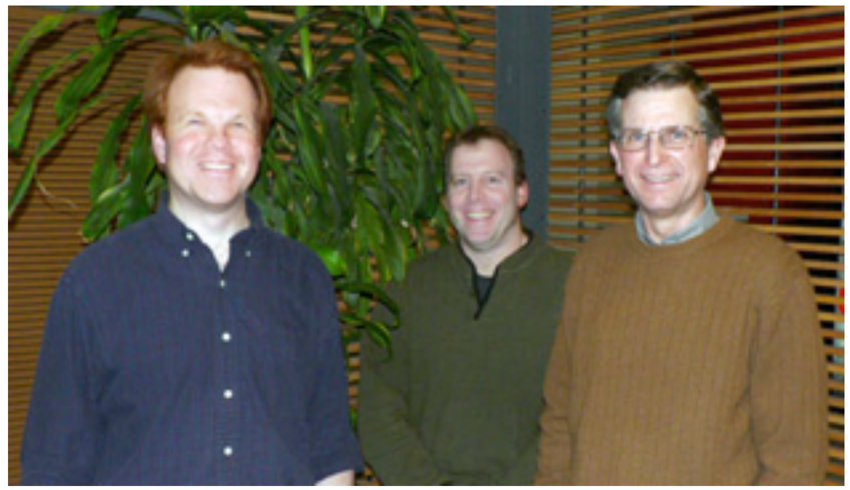
Collaborators



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Questions?

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