Software Support for Improving Technology Infusion

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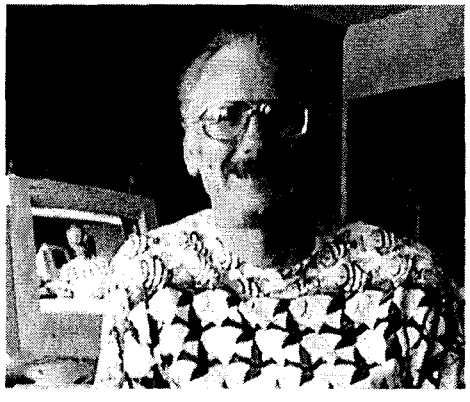

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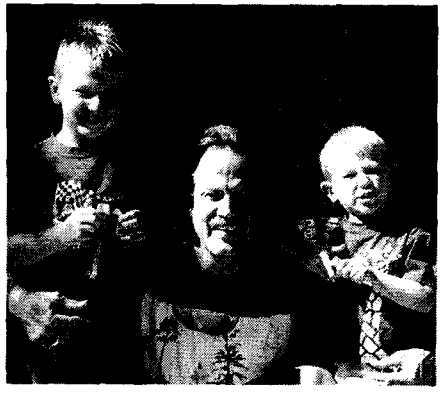


Technology Infusion Impediments

New mission concepts enabled by new technologies (autonomy, agents, ...), but...

Infusion of advanced technologies problematic :

- **Requirements-related:** Miscommunicated, misunderstood or under-defined customer (mission) requirements
- **Readiness-related:** Technology deemed non-flightworthy (unforeseen unresolved engineering issues)
- **Competitiveness-related:** Near-equivalent technologies are or will become available

Needs:

Clearer definition of mission requirements

Early identification of technology-specific engineering difficulties

Ability to decide among architectures, technologies

Projected status of competing technologies

note: these all apply to many areas, not just space!

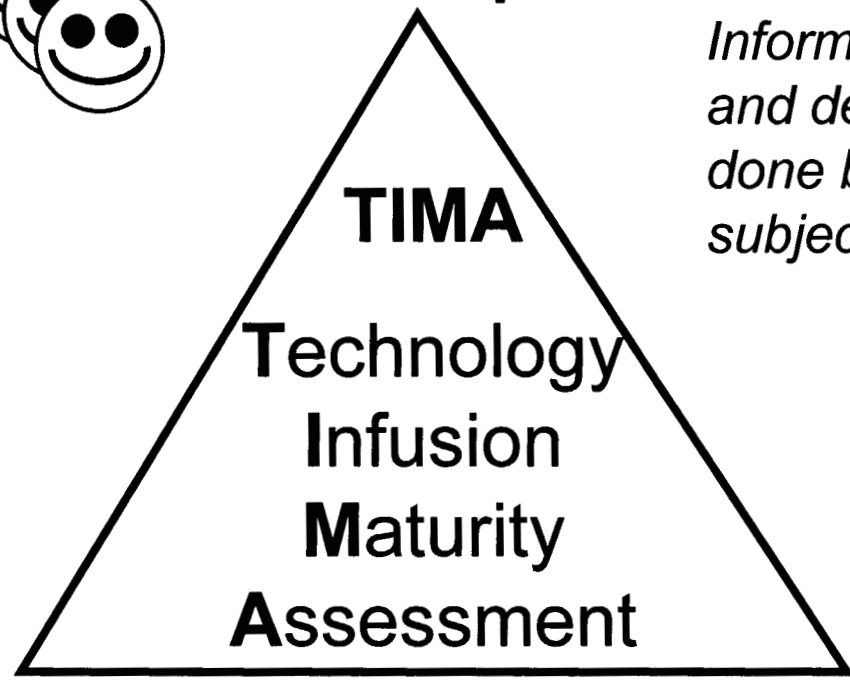
Challenges:

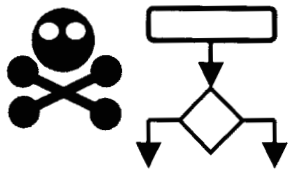
- **Multi-disciplinary nature:**
  No individual expert in all areas; No individual can juggle all details at once
- **Groundbreaking nature of new mission concepts and autonomies:**
  Past experience provides only a partial guide
- **Resource constrained:**
  Many risks that, if untamed, lead to abandonment or wasted resources
- **Need good decisions early:**
  Early on, lack information (e.g., detailed design) on which to base decisions

Expertise + Process + Software

Human Expertise

Information gathering and decision making done by relevant subject area experts





Risk-Based Process

Stakeholders → Requirements → Risks → Mitigations → Costs → Selection → Documentation

Software Support

Information repository, Calculations, Visualizations, Decision Support

JPL TIMA process: Risk-based Roadmapping

What do you want?

"**Objectives**"
"Requirements"
"Goals"

Mick Jagger
(Rolling Stones):

"You can't always get what you want"

Descoping – strategic abandonment of objectives.

Reprioritize objectives; primary, secondary…

Determine attainment if given additional resources ($, mass, …)

What can get in the way?

"**Risks**"
"Failure Modes"
"Defects"

Dr. Michael Greenfield
(NASA HQ):

"Risk as a resource"

Trade risk for other resources.

Use risk as an intermediary between other resources.

Issues outside of technologist expertise.

Issues unique to flight development.

What can you do about it?

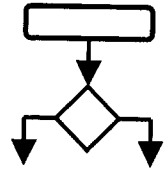
"**Mitigations**"
"Solution Options"
"Preventions, Analyses, Controls,Tests – PACTs"

Matt Landano
(JPL):

"Do the right thing & do it right"

Can't afford all possible mitigations, so must choose judiciously.

Know the purpose(s) of each mitigation.



Day 1 – day of the pessimists!

Objectives – *what you want*

Risks* – *what could occur to detract from attaining objectives*

Impact (Objective x Risk) - *proportion of the Objective lost if Risk occurs*

* ***All*** risks, ***including*** those whose mitigation is planned:

- Makes available for scrutiny explicit assertions of risk reduction
- Allows risk and its mitigation to be involved in trades
- Reveals dependencies on mitigations (what if can't do it on time?)

Day 2 – day of the optimists!

Mitigations – *what could be done to reduce risk*

Effect (Mitigation x Risk) – *proportion by which Mitigation reduces Risk*

Experts' estimates, past experience if available, models & simulations…

Day 3 – day of the realists!

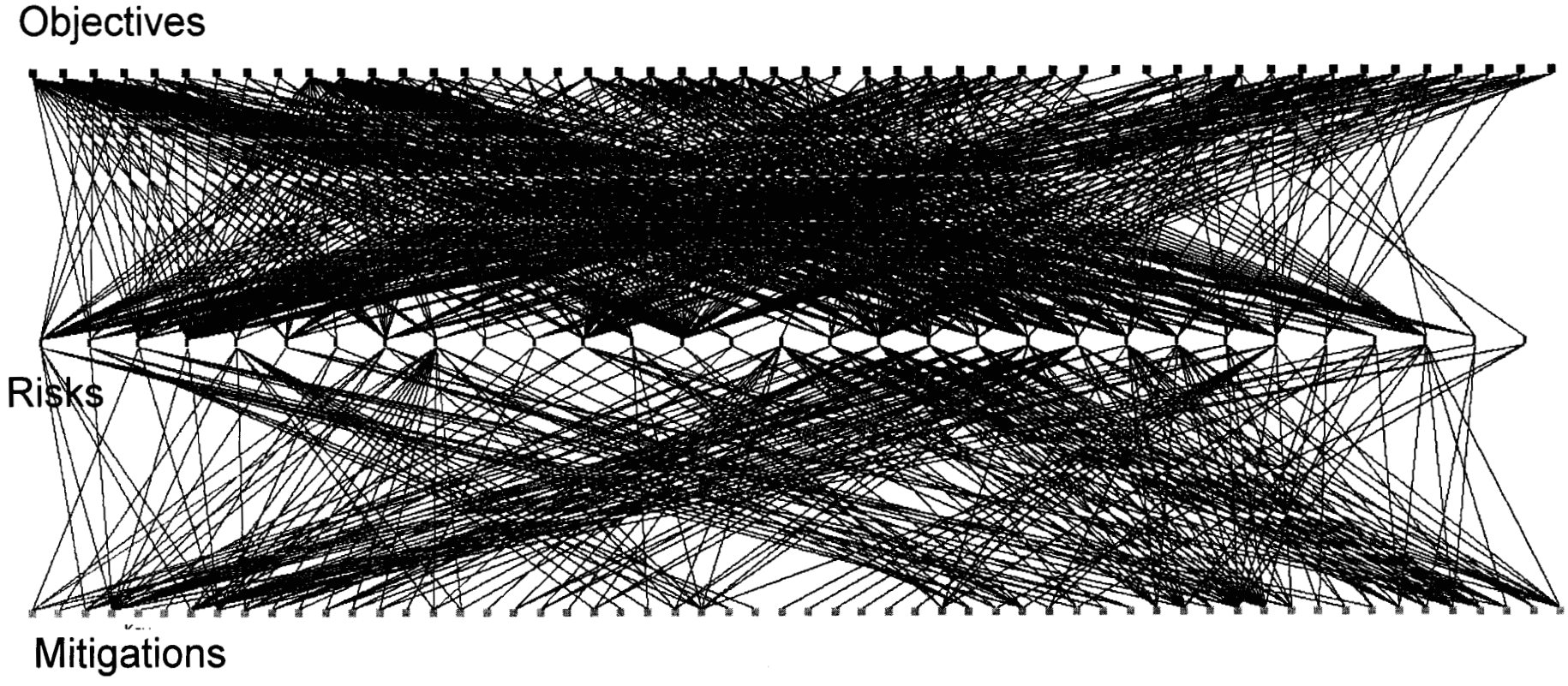
Select – Mitigations to perform
Objectives to discard
Resources to ask for

Decision-making guided by accumulated information

Getting the right people is key!!!

Mission scientists, technologists, relevant disciplines' engineers, assembly/integration, testing, QA, operation, programmatics

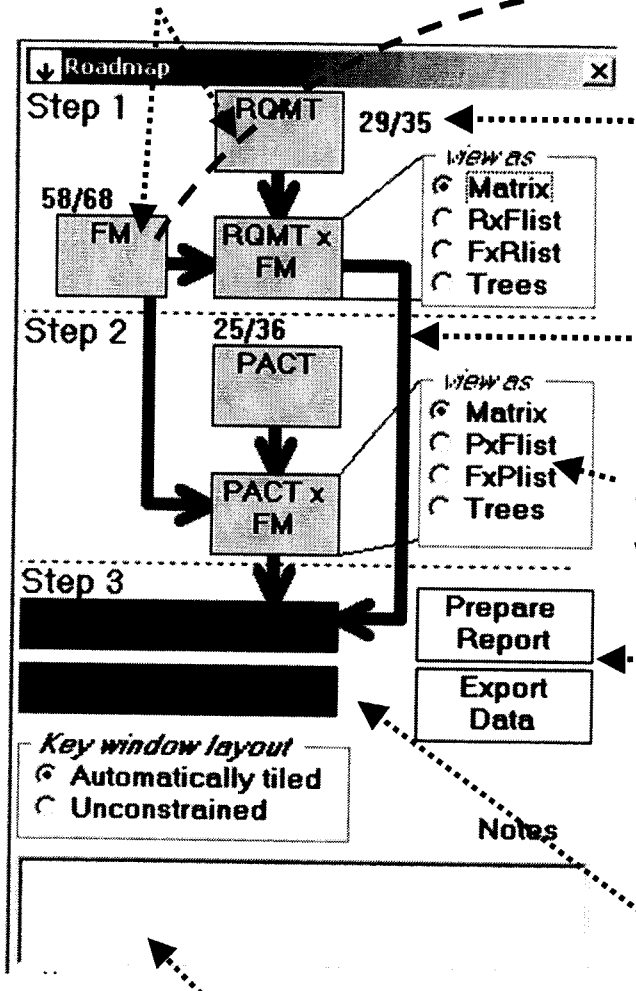
Software Necessary!!!
typical DDP information set:
50 objectives, 31 risks, 58 mitigations



DDP process and *custom software* enables models of this scale to be *built* and *used* effectively

Flexible Process Support

Sets of information needed for the TIMA process



Status info

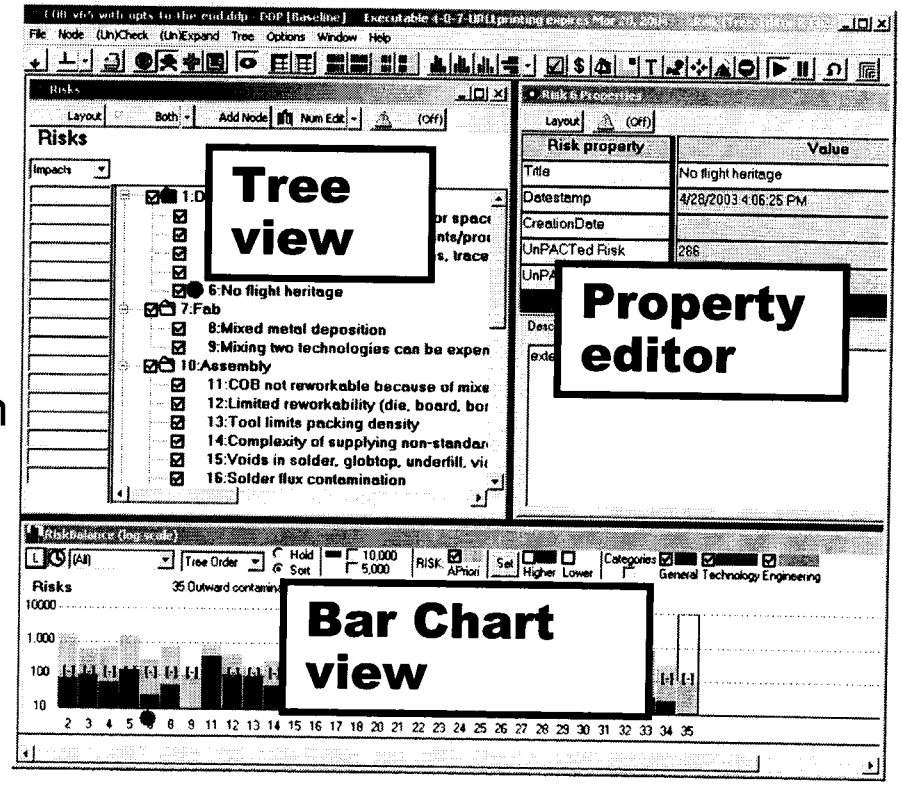
Nominal TIMA process flow

Choice of visualization

Export TIMA information

Decision making assistance

Notes to track TBDs, progress, etc



Straightforward conceptual data

TREES of Objectives, Risks & Mitigations

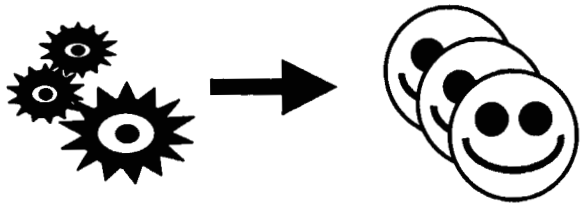
RELATIONSHIPS (LINKS) between Objectives & Risks ("Impacts") and between Mitigations and Risks ("Effects")

ATTRIBUTES for the details, e.g., title (string), value (number/string), description (text), …

Upward-compatible extensions over time (e.g., "time phase" of Mitigations)

Calculations fast for now, scale-up becoming an issue

Standard Visualizations

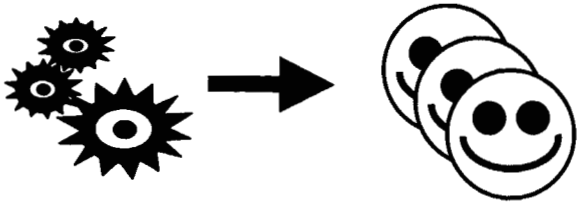


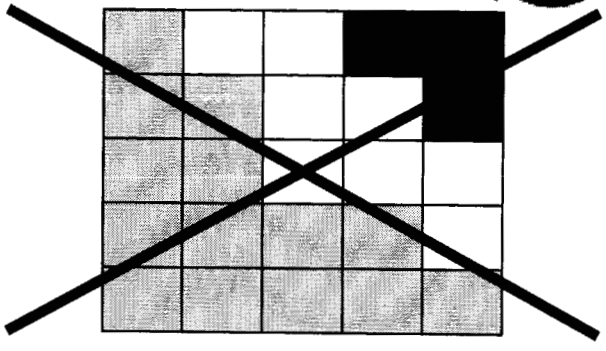
TREES, MATRICES, BAR CHARTS

Multiple views:

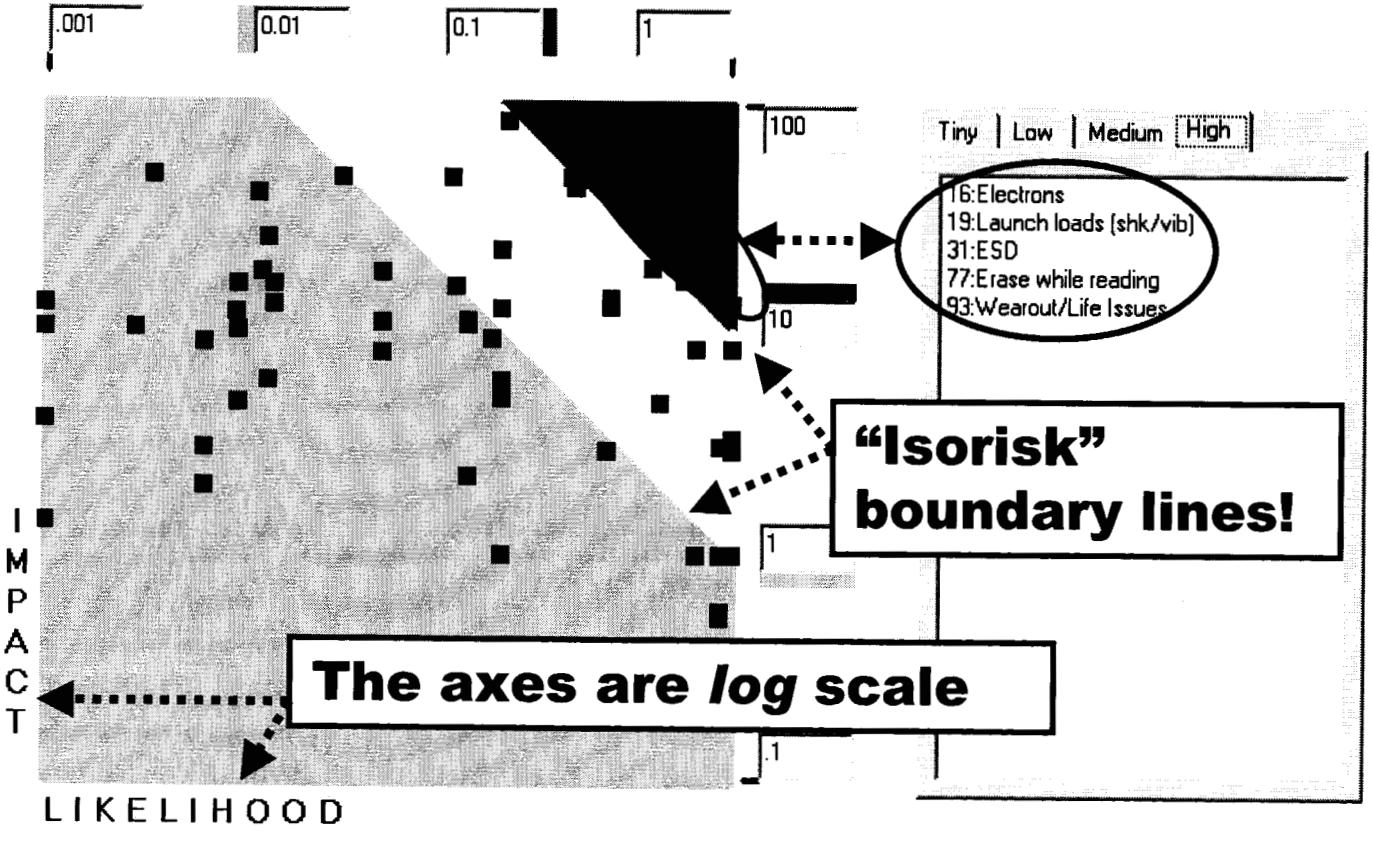
- Uniform color conventions
- “Focus” to draw attention, span leap view to view
- Views kept in correspondence

Custom Visualizations: risk chart



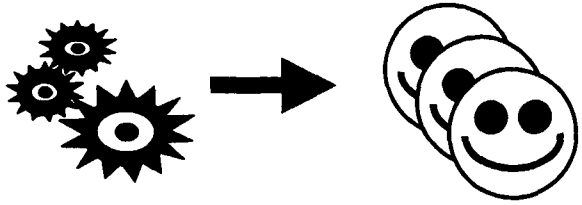


Risk = impact x likelihood



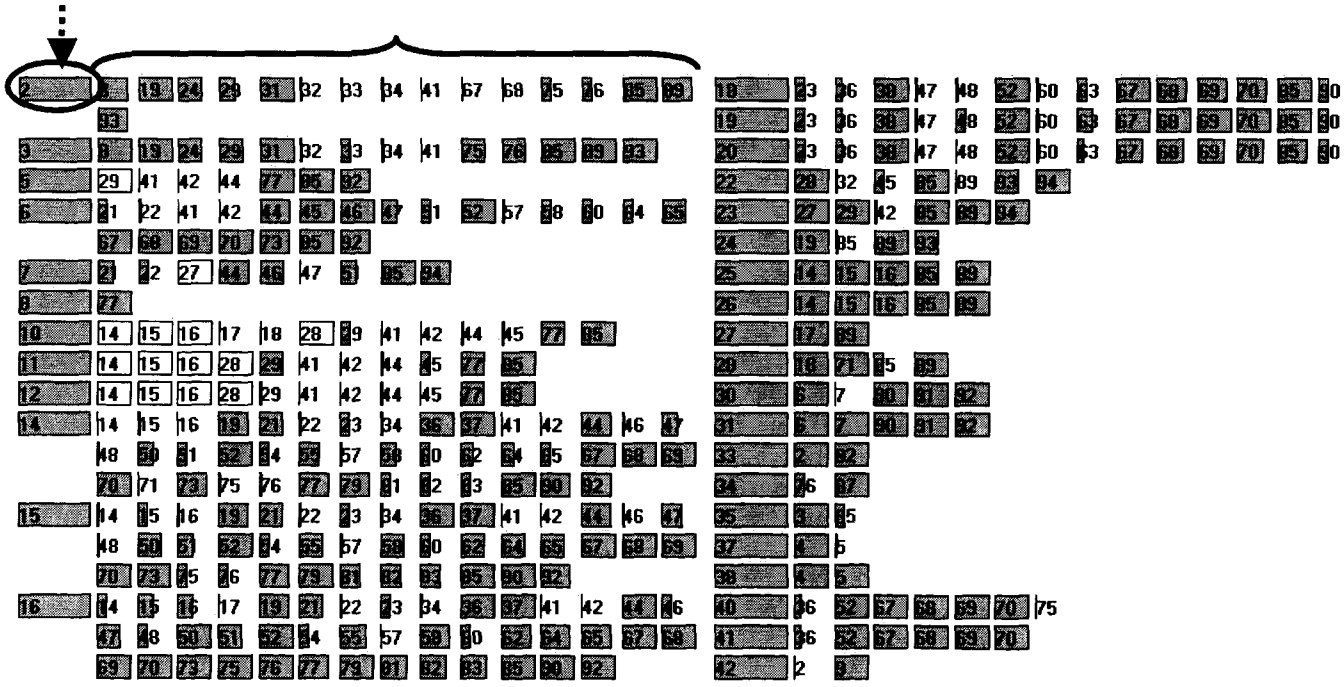
When you've got numbers, make use of them!

Custom Visualizations: "stem-and-leaf" for sparse matrix



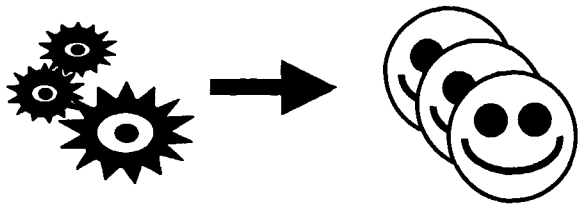
Dilemma: inevitably more information than can readily fit onto one screen...

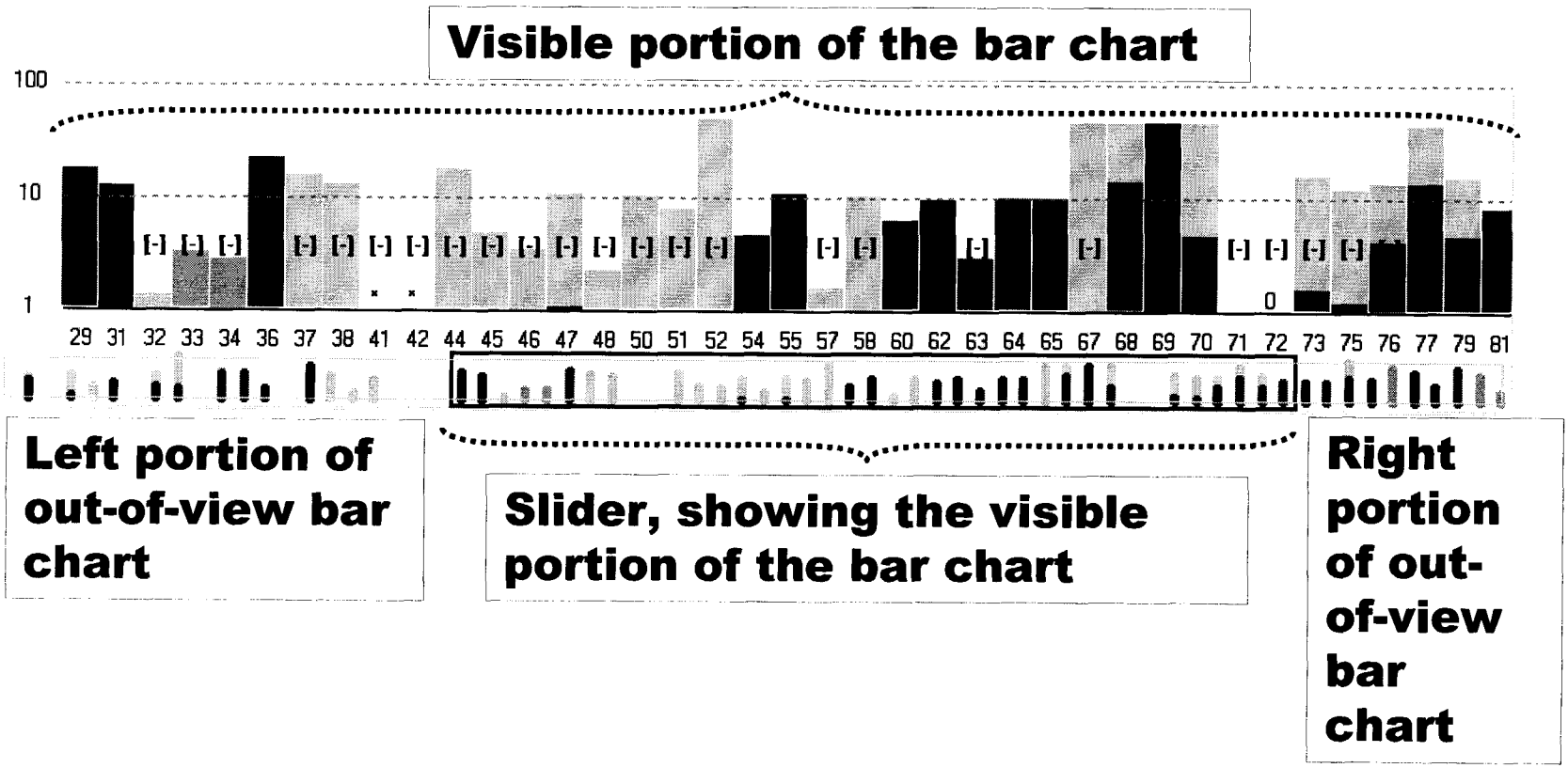
Objectives | **Impacts of Risks on Objective**



Extends work of JPLers Howard & Hartsough

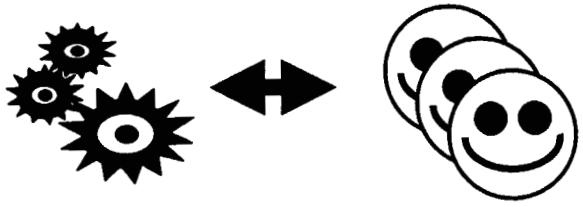
Custom Visualizations: scroll bar is bar chart in miniature!





Inspired by Edward Tufte!

Assisted Decision Making



58 Mitigations, each an independent choice

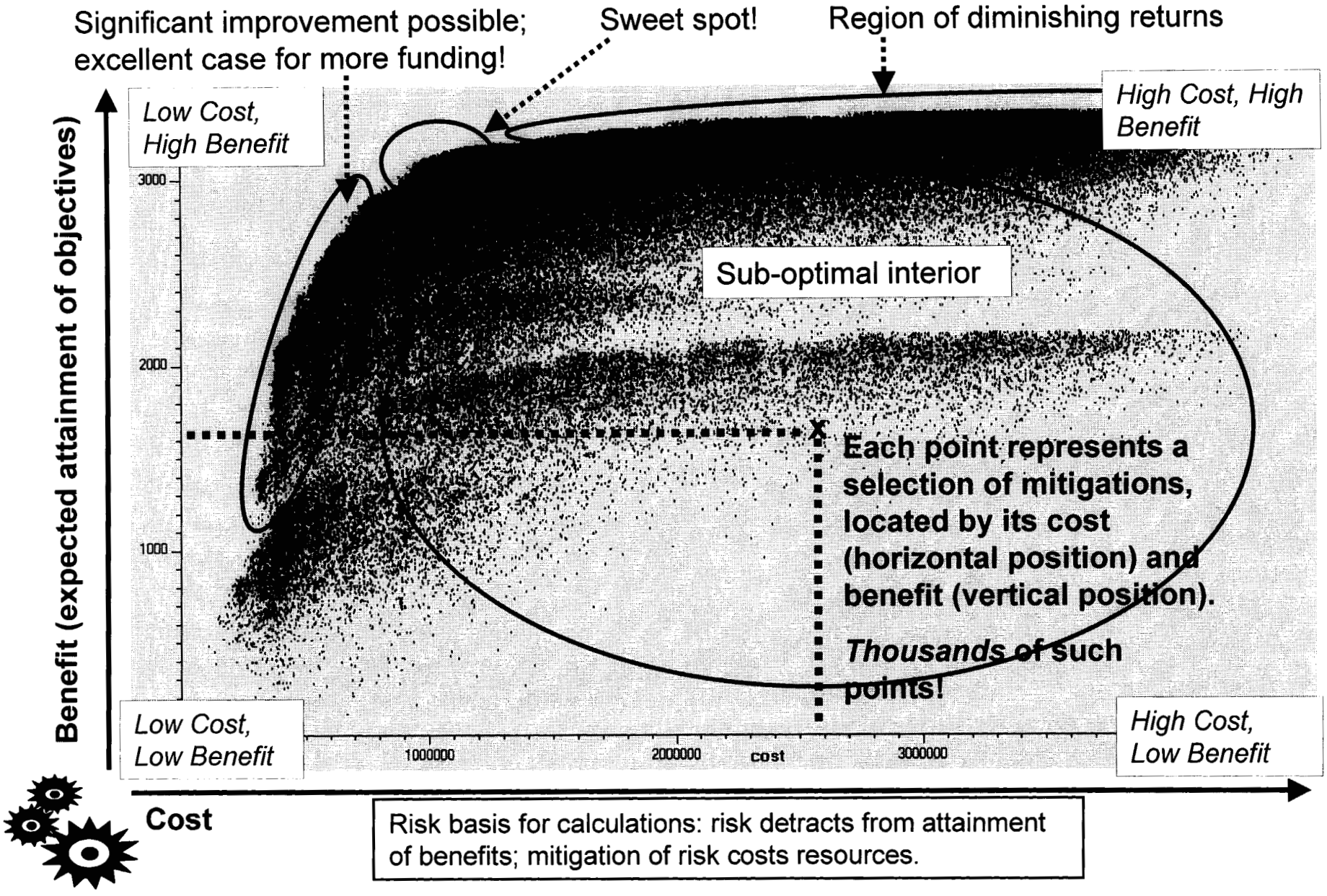
2^{58} (approx 10^{18}) ways of choosing!

Heuristic search:

- Simulated Annealing – included in DDP tool
- Genetic Algorithms – included in Java prototype
- Machine Learning – successful experiments

Cost-Benefit trade space insights

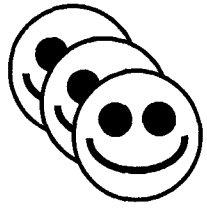
58 mitigations = 2^{58} (approx 10^{18}) ways of selecting.
Simulated Annealing used to search for near-optimal selections.



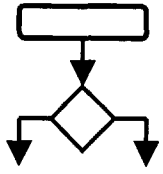
Risk basis for calculations: risk detracts from attainment of benefits; mitigation of risk costs resources.

CONCLUDING SUMMARY

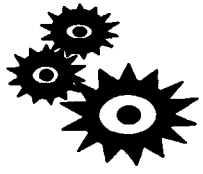
- **Information: make most use of information available early in lifecycle**
  - Combine knowledge from experts and past experience
  - Accommodate both evidence and estimates



- **Process: gather the right information the right way**
  - Objectives, including their relative importance
  - Risks, and by how much they impact objectives and requirements
  - Mitigations, and by how much their use would reduce risk



- **Tool support: effectively handle voluminous amounts of information**
  - Capture experts' knowledge on-the-fly during intensive sessions
  - Present information through cogent visualizations
  - Derive additional knowledge via calculation and search



- **NET RESULT: Utilizable Products:**
  - Specific collection of tasks, purposeful, costed, scheduled
  - A traceable rationale, quantitative scoring, reviewable
  - Risk-based understanding, thorough, calibrated

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