Valuing Space Missions

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Not an Easy Problem

There are many reasons why assessing the value of proposed NASA missions is a difficult problem...

- Fundamentally uncertain results of each mission
- Vast range of missions that NASA considers
- Different objectives matter to different stakeholders
- Difficult to translate between objectives such as "scientific advance" and "dollars spent"
- Intricate relationships between present and future missions

Why bother assessing mission value? How will this help NASA?

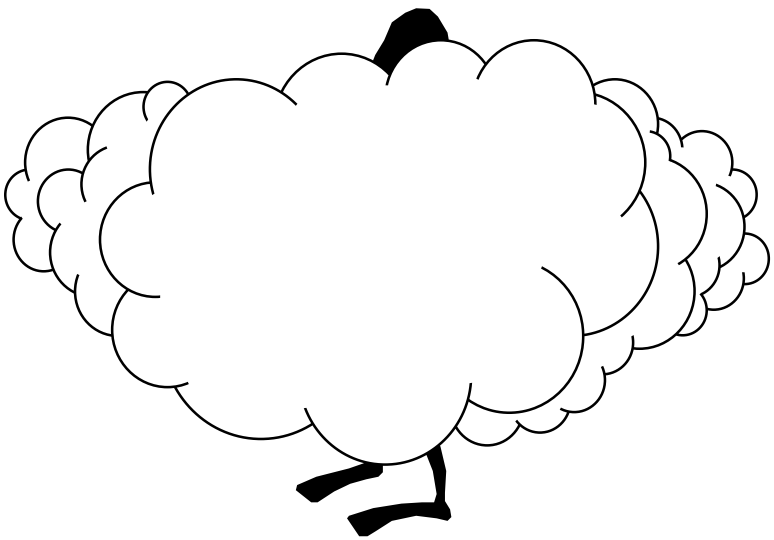
A Decision-Making Tool

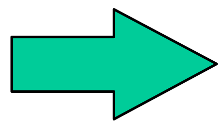
This methodology will help NASA make several types of decisions, including...

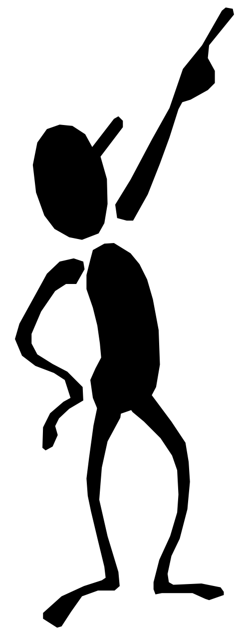
- Project comparison
  - Should NASA fund Mission X or Mission Y?
- Project scoping
  - Should Mission X include Instrument A, Instrument B or both?
- Project timing
  - Should Mission X launch in 2004 or 2006?

Our Goal

To add clarity by articulating a decision basis for NASA mission selection...







Status Quo

- Fuzzy
- Political
- Focus on alternatives instead of outcomes

Goal

- Clear
- Strictly merit-based
- Adhere to norms of decision analysis

From Specifications to Objectives

This methodology translates a mission's specifications into how well it will meet NASA objectives...

SPECIFICATIONS

- Destination
- Launch date
- Duration
- Instrumentation
- Measurements
- New technology
- Cost

OBJECTIVES

- Advancement of science
- Applications for society
- Public reaction
- Effect on future missions
- Cost

Methodology Overview

This methodology requires both global and local analysis...

- Global questions (for NASA as a whole)
  - What are NASA’s fundamental objectives?
  - What are appropriate scales for measuring these objectives?
  - What are these objectives’ relative importance?
- Local questions (for each proposed mission)
  - What are the possible outcomes of a mission?
  - How likely is each outcome?
  - How well does each outcome meet NASA objectives?

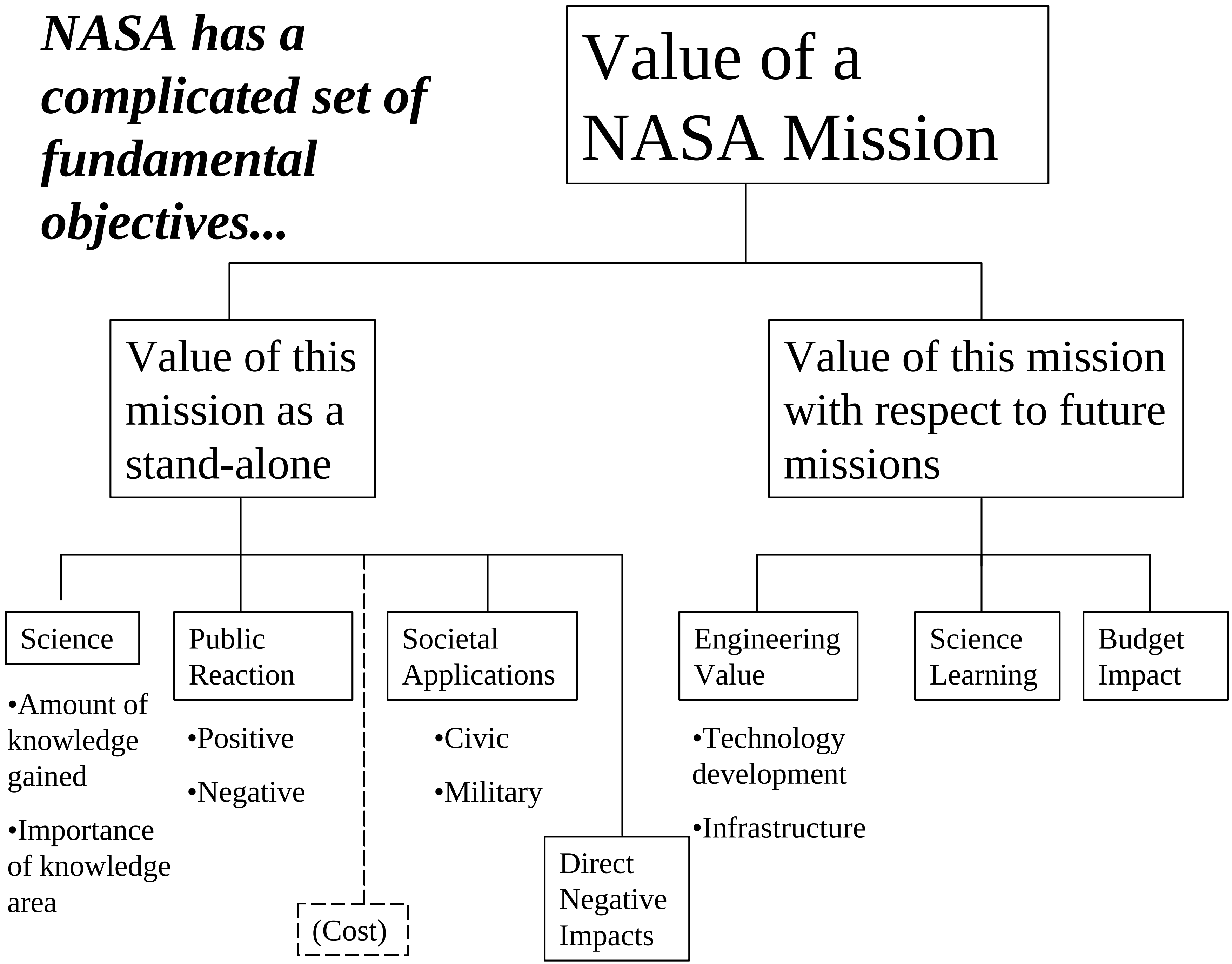
Global Step One - Identify NASA's Fundamental Objectives

We try to capture all possible sources of value that a mission can provide...

- Include all NASA perspectives
- Iterative process to develop objective hierarchy

Next slide: Our current model of NASA's objectives

NASA has a complicated set of fundamental objectives...



Global Step Two - Construct Scales to Measure Attainment of Objectives

There is an art to constructing useful scales...

- Scales measure specific outcomes, not whole missions
  - Combine scores later to calculate value of mission as a whole
- Construct scales for easy assessment
  - Discrete scales
  - Clear verbal descriptions
  - Examples for each level of attainment

Quantifying Scientific Learning

We can use a subjective approach to quantify the learning associated with any prospect...

Scale One

Amount of knowledge gained:

Highest: The research addresses phenomena not previously studied. The research delivers a step-function advancement in knowledge, both qualitatively and quantitatively. (e.g., analysis of a new type of star)

Lowest: The research produces no new knowledge. (e.g., mission explodes at launch)

Scale Two

Importance of knowledge area:

Highest: Research area is of recognized importance throughout the scientific community (e.g., expansion/contraction of universe).

Lowest: Research area is important to no one in scientific community (e.g., effect of space missions on biorhythms)

Learning Quantification - Example

Amount of Knowledge Gained	Low importance	High importance
High	Constructing first map of Phobos (a moon of Mars)	Constructing first map of Mars
Low	Refining map of Phobos with new details	Refining map of Mars with new details

Low High

Importance of Knowledge Area

Global Step Three - Put Numbers on Value Scales

We use numbers to quantify NASA's preferences within and between objectives...

- Within an objective
  - How much better is a good outcome than a mediocre outcome? Than a bad outcome?
- Between objectives
  - How does a good outcome in Objective X compare to a good outcome in Objective Y?
- Numerical quantification of subjective preferences
  - Enables easy sensitivity analysis

Mission-Specific Analysis

We assess how well a particular mission will achieve NASA's fundamental objectives...

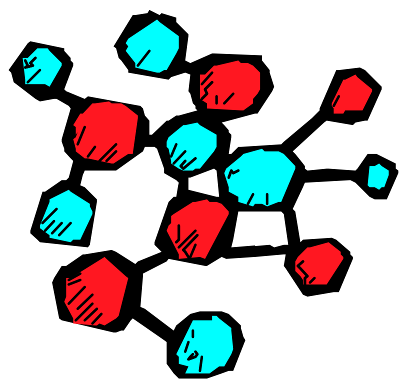
- What are the possible outcomes of the mission?
- How likely is each outcome?
- How well does each outcome meet NASA objectives?

- Use probabilistic modeling to characterize possible mission outcomes
- Combine likelihood and value of each outcome to calculate overall value of mission

Decomposing Probabilities

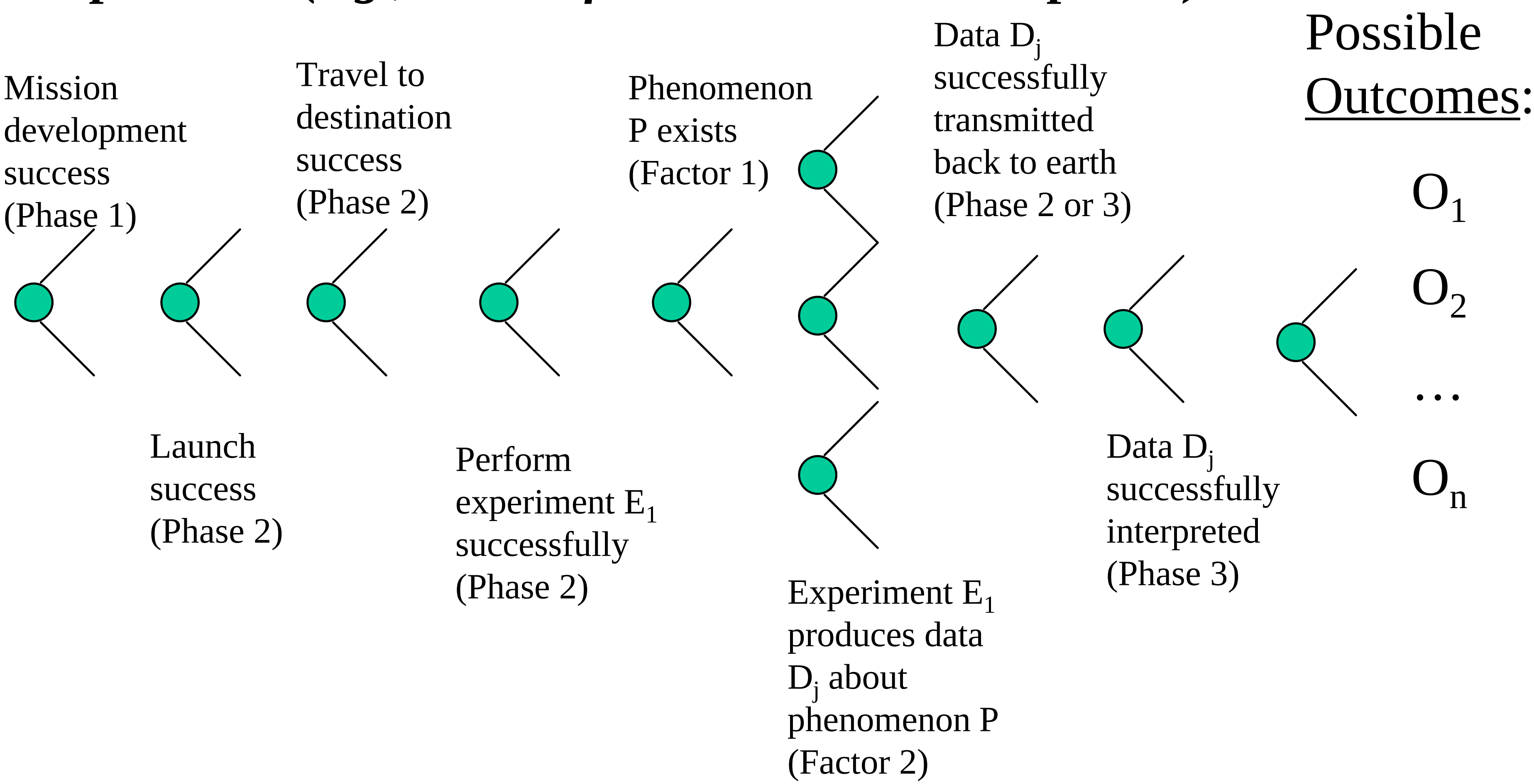
We can estimate the probabilities of an outcome by analyzing the steps along the way to that outcome...

- "Engineering" distinctions
  - Phase 1: Development of mission
  - Phase 2: Performance of mission
  - Phase 3: Interpretation of data from mission
- "Scientific" distinctions
  - Factor 1: Existence of phenomenon
  - Factor 2: Given that phenomenon exists and mission works, mission finds phenomenon



Constructing Event Trees

Example: Component distinctions for a typical NASA experiment (e.g., to look for water on another planet)...



Note: We can extend this approach to include other factors (e.g., applications).

A Problem?

What if we don't know all of the possible outcomes? How can we predict the unpredictable?...

From the S.F. Chronicle, 5/19/99, p.A4, "NASA Institute's Metaphysical Mission":

Both Goldin and Blumberg stressed that they cannot begin to predict what life may be like and how it originated elsewhere in the universe. When a reporter asked Blumberg, "How do you look for something if you don't even know what it is?" he replied - to appreciative laughter from the scientists in his audience - "That's just what basic research is all about."

(Baruch Blumberg - Nobel Laureate - Director of NASA's Astrobiology Institute)

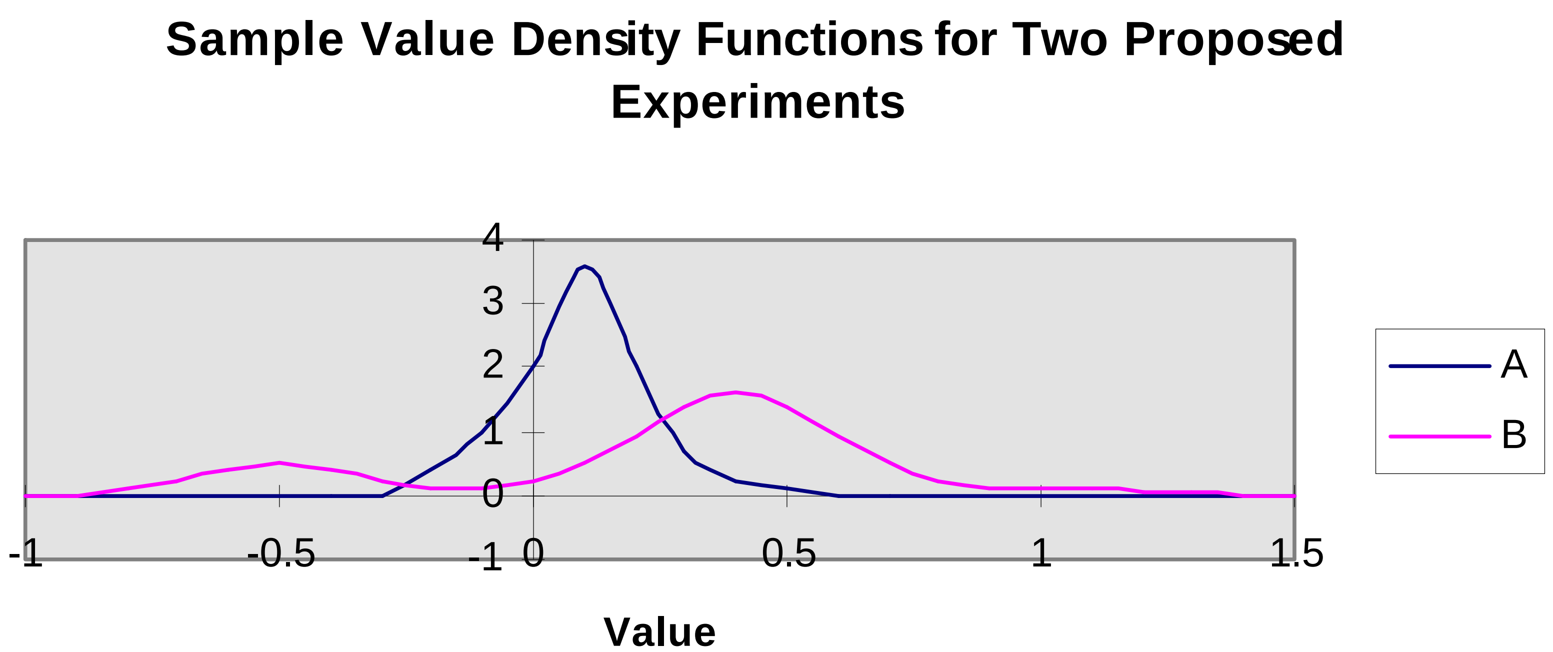
Predicting the Unpredictable

What if we don't know all of the possible outcomes? How can we predict the unpredictable?...

- Impossible to fully characterize specifics of all possible outcomes
  - Unnecessary to do so
- Instead, need to fully characterize a learning value distribution to "expect the unexpected," considering:
  - "Bandwidth" of instruments
  - "Freshness" of subject matter
  - Novelty of experimental approach
- Can adjust degrees of information distinctions to reflect this
  - Phase 3, Factor 1, Factor 2
- Alternatively, can make post hoc qualitative adjustments to value distribution

Predicting the Unpredictable

We can characterize possible learning with our subjective scales, without specifically identifying what it is that we might learn...



Two Important Open Questions

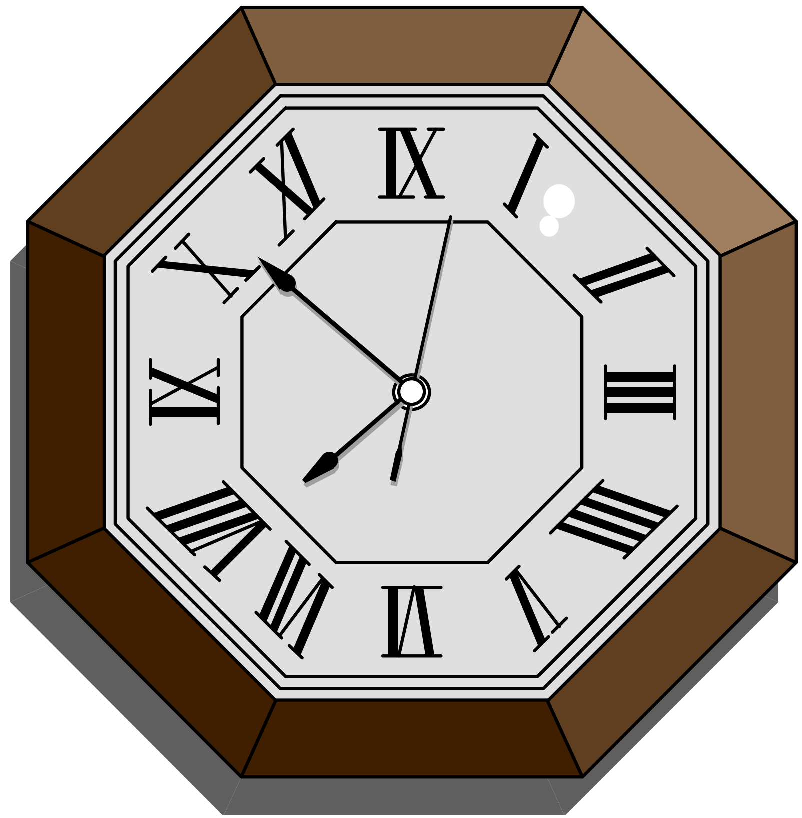
To help NASA make good decisions, we must understand its attitude towards cost and time...

- What is NASA's willingness-to-pay for achieving its objectives?
  - Is this affected by NASA's fixed-budget environment?
- How does NASA value results today vs. results tomorrow?
  - May be different for different objectives

Why Model Time?

Timing is often a characteristic of the alternatives faced...

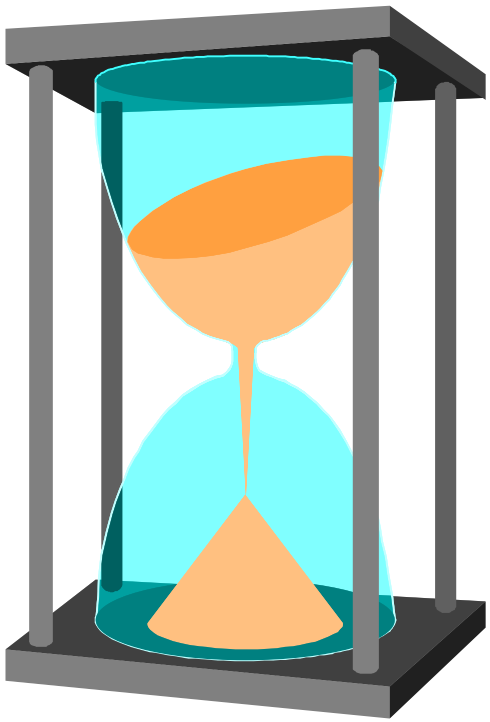
- For a single experiment
  - Today or tomorrow
  - Fast-track or slow-track
- Between two experiments
  - Different lengths
- Window of availability
  - Pluto
  - Scheduling opportunity



- We need to account for the role of time

Why Change the Timing?

An administrator may accelerate or delay an experiment for many reasons...

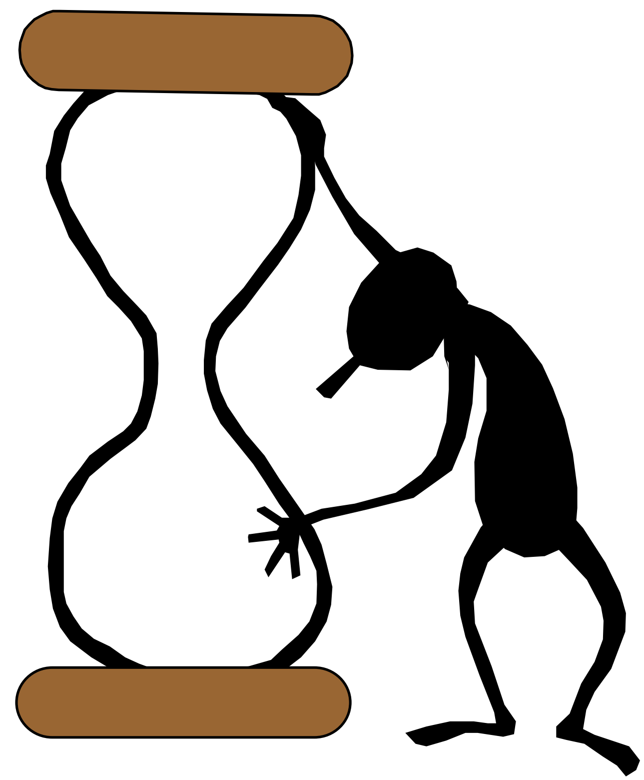


- Budget limitations
  - Unable to run all good experiments at once
- Cost
  - Experiment might be cheaper then (or now)
- Likelihood of success
  - Future experiment may benefit from improved technology, know-how
- "Ripeness for exploration"
  - Strike while the iron is hot
  - Wait until the field has matured enough to appreciate results

The Time Value of Knowledge

It is better to know something sooner rather than later...

- We value learning in and of itself
- Knowledge is not an expendable resource
- Today's knowledge is the seed for tomorrow's learning
- New experimental knowledge eventually loses its importance

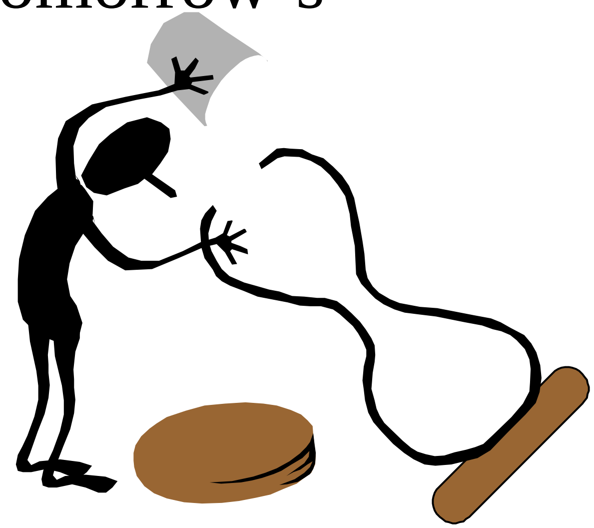


- Can we understand the dynamics of the time-value of knowledge?

Three Factors

We propose three factors that influence the time-value of knowledge...

- A single experiment’s contribution to knowledge fades over time
  - – Obsolescence rate - h(t)
- Today’s knowledge is the seed for tomorrow’s learning: diminishing ripples
  - – Ripple speed and breadth - f(t)
  - – Ripple damping - g(t)



- What influences these factors?
- Can we build a reasonable model of this?