# An Architecting Book of Knowledge (BoK) to Improve Architectural Decision-Making

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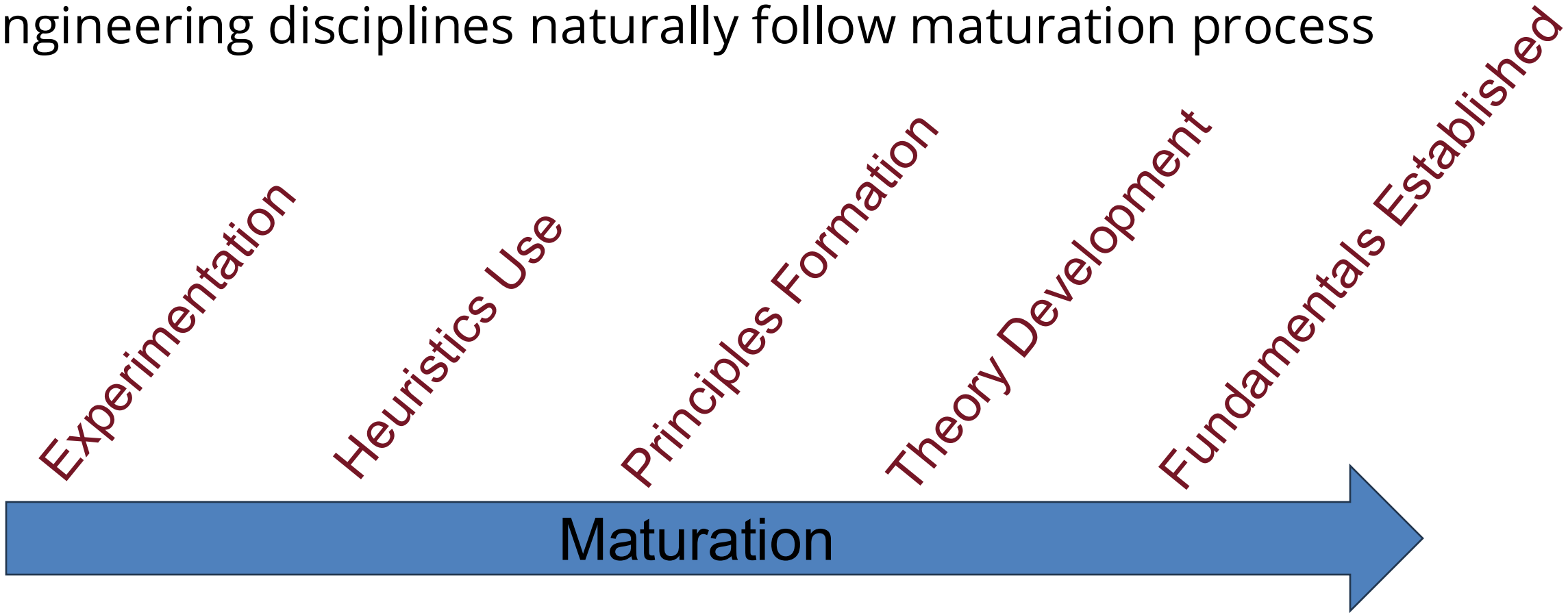
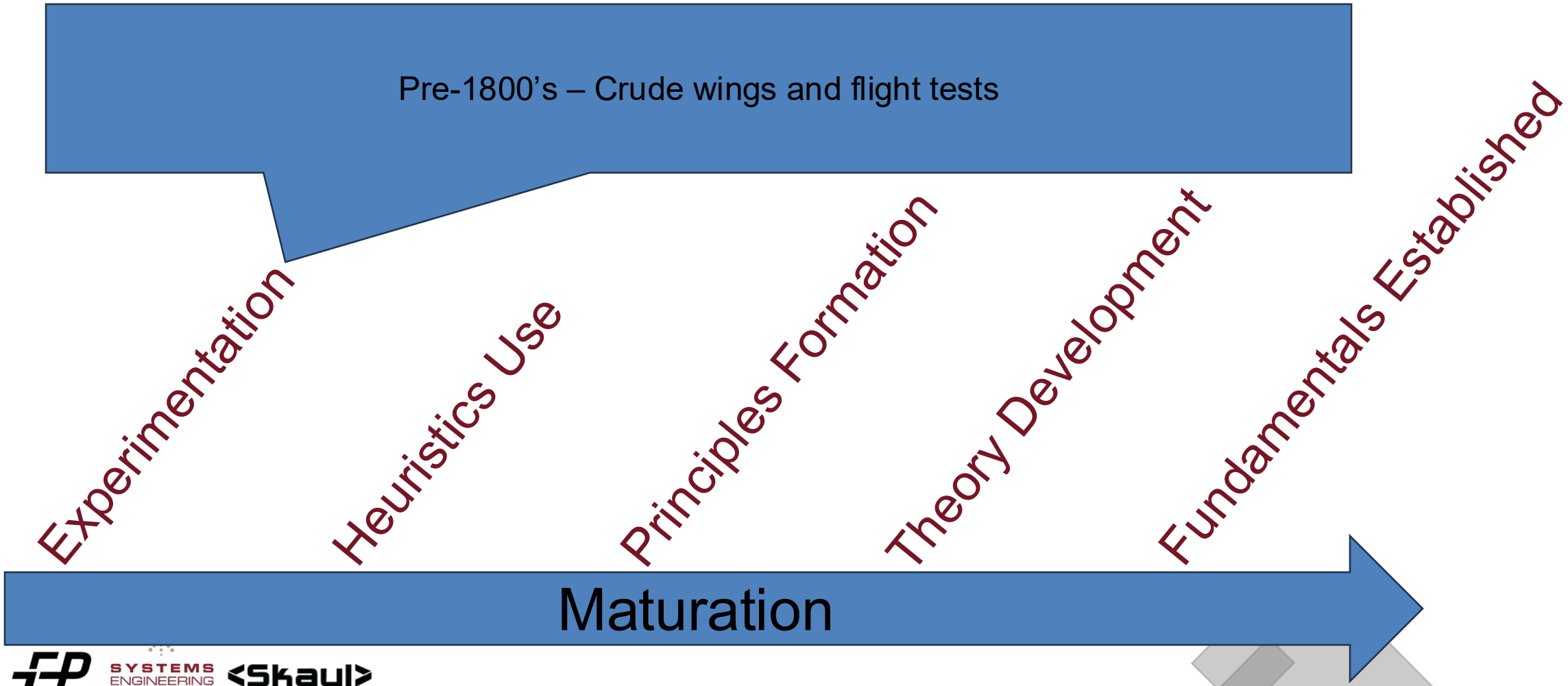
# Motivation

- Engineering disciplines naturally follow maturation process



# Motivation

- Aerospace Engineering Example



# Motivation

- Aerospace Engineering Example

Late 1800's – Trial and Error identify wing shapes that work

Experimentation

Heuristics Use

Principles Formation

Theory Development

Fundamentals Established

Maturation

Image: https://www.faa.gov/about/history/timeline; accessed 11/2/24

# Motivation

- Aerospace Engineering Example

Early 1900's – Community agreement on wing characteristics producing certain behaviors

Experimentation

Heuristics Use

Principles Formation

Theory Development

Fundamentals Established

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# Motivation

- Aerospace Engineering Example

Mid 1900's – Scientific understanding of lift with equations and evidence

Experimentation

Heuristics Use

Principles Formation

Theory Development

Fundamentals Established

Maturation

Image: https://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/shape.html ; accessed 11/2/24

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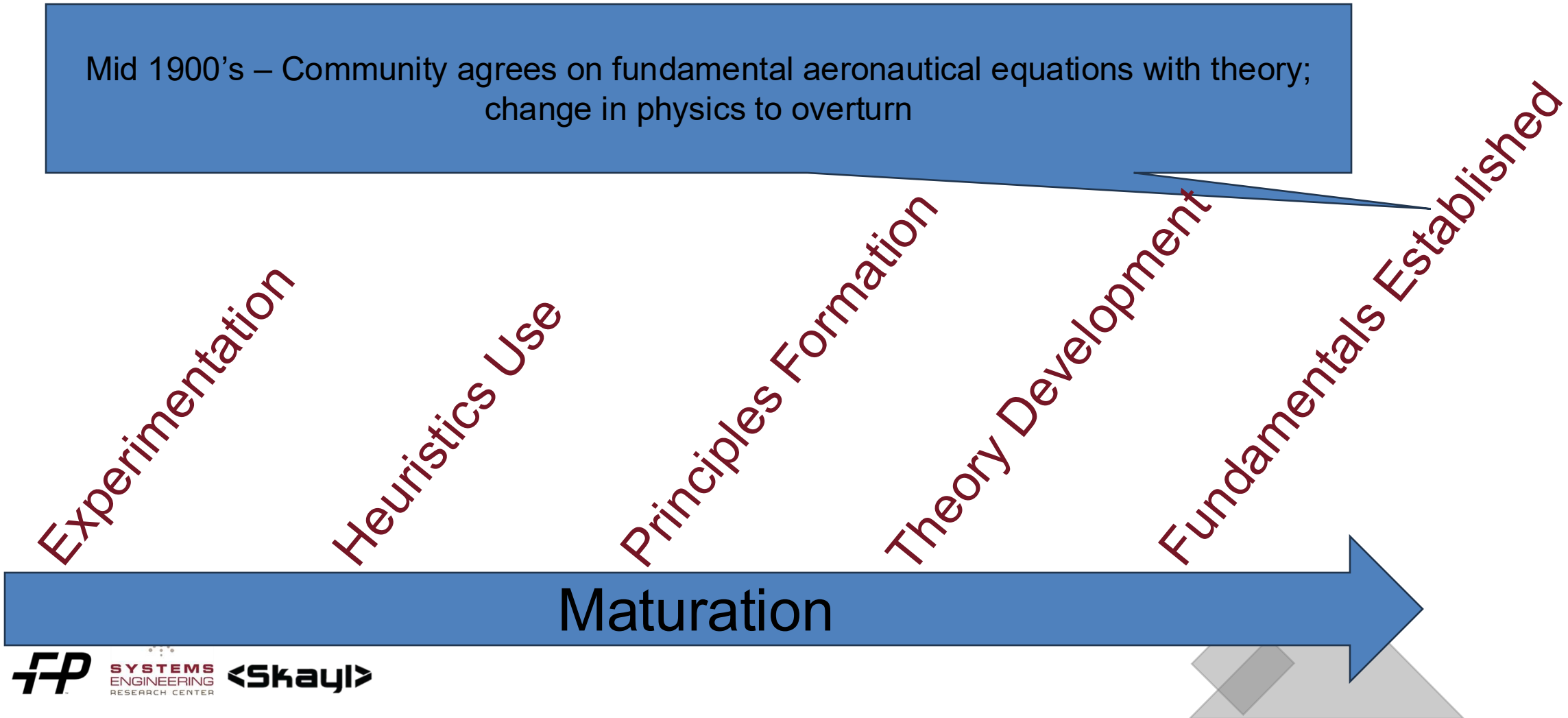
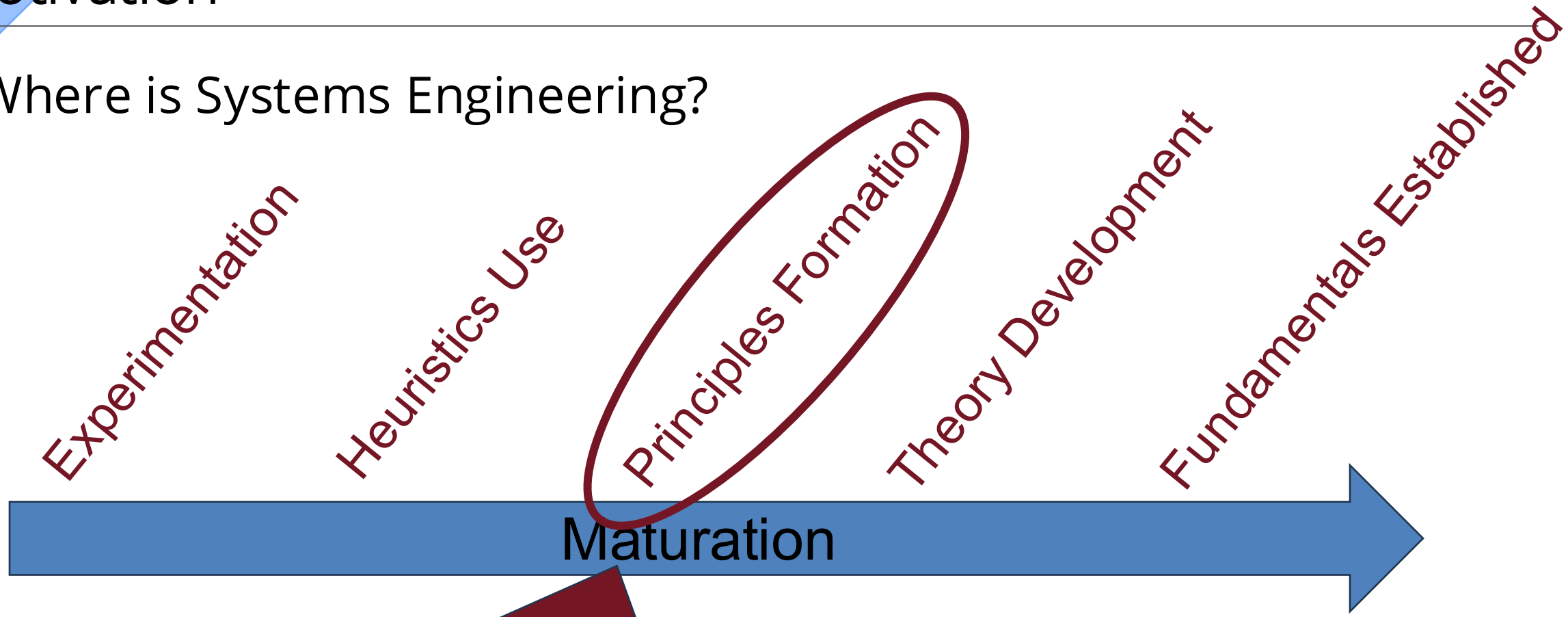
- Aerospace Engineering Example



# Motivation

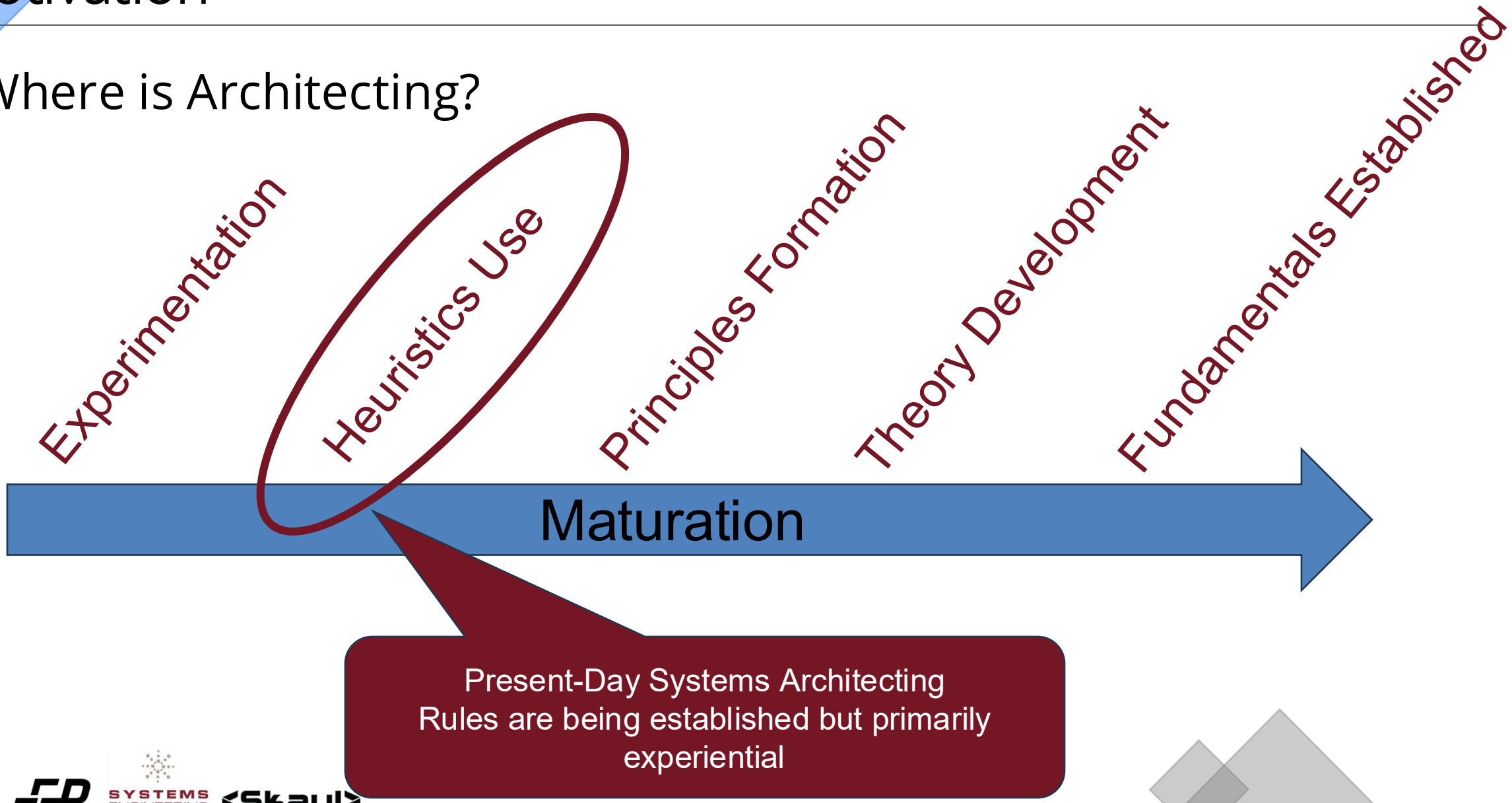
- Where is Systems Engineering?




Present-Day Systems Engineering
Knowledge has enough evidence to be used with some assurance in a repeatable and predictable manner

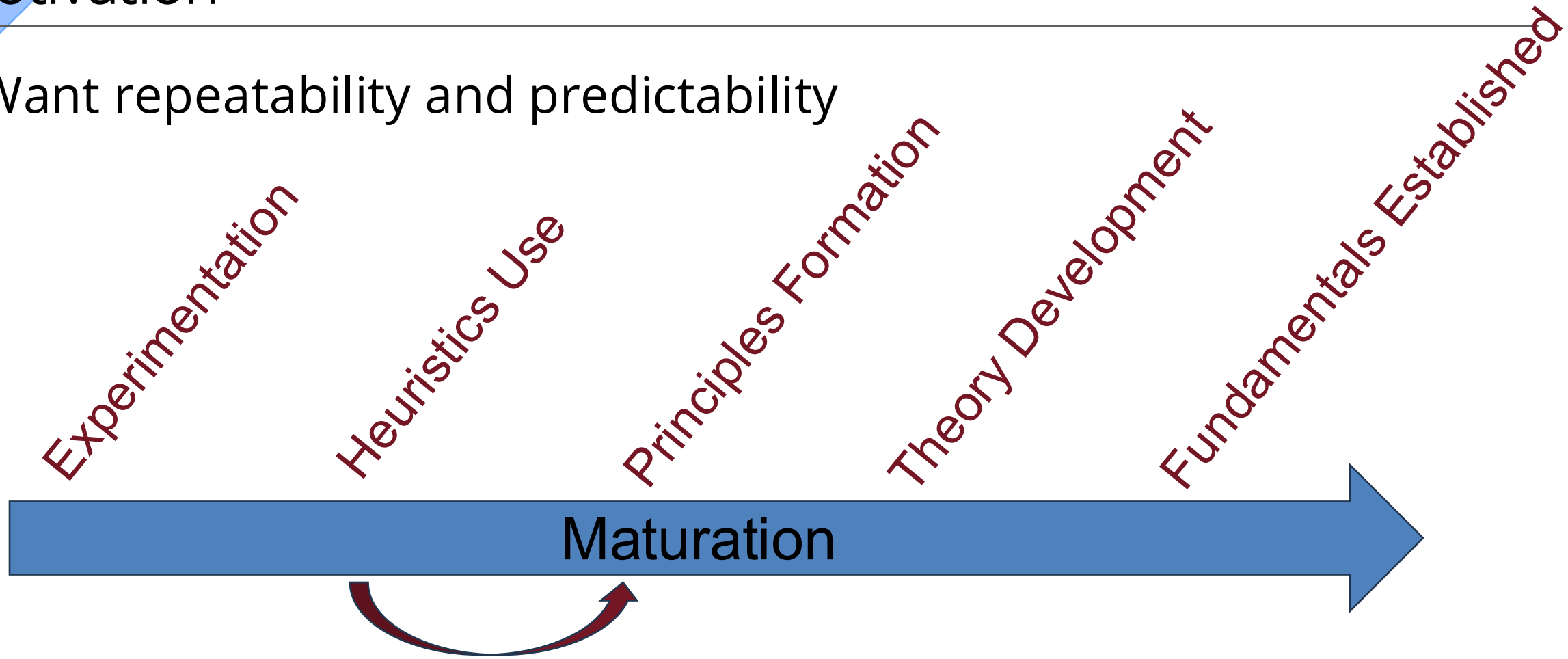
# Motivation

- Where is Architecting?



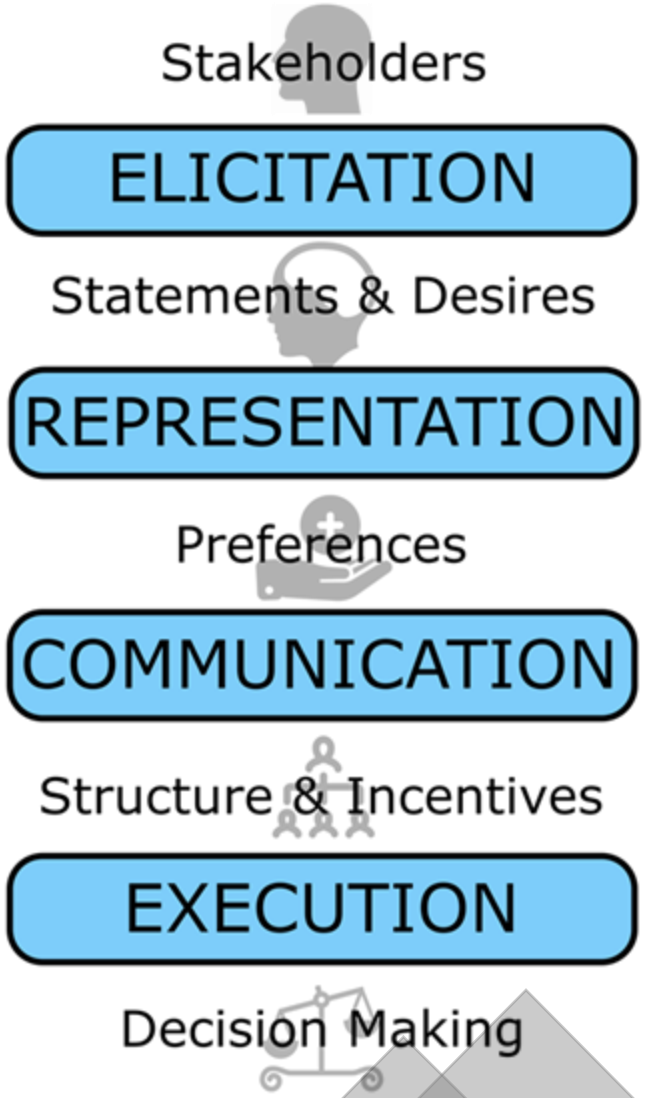
# Motivation

- Want repeatability and predictability



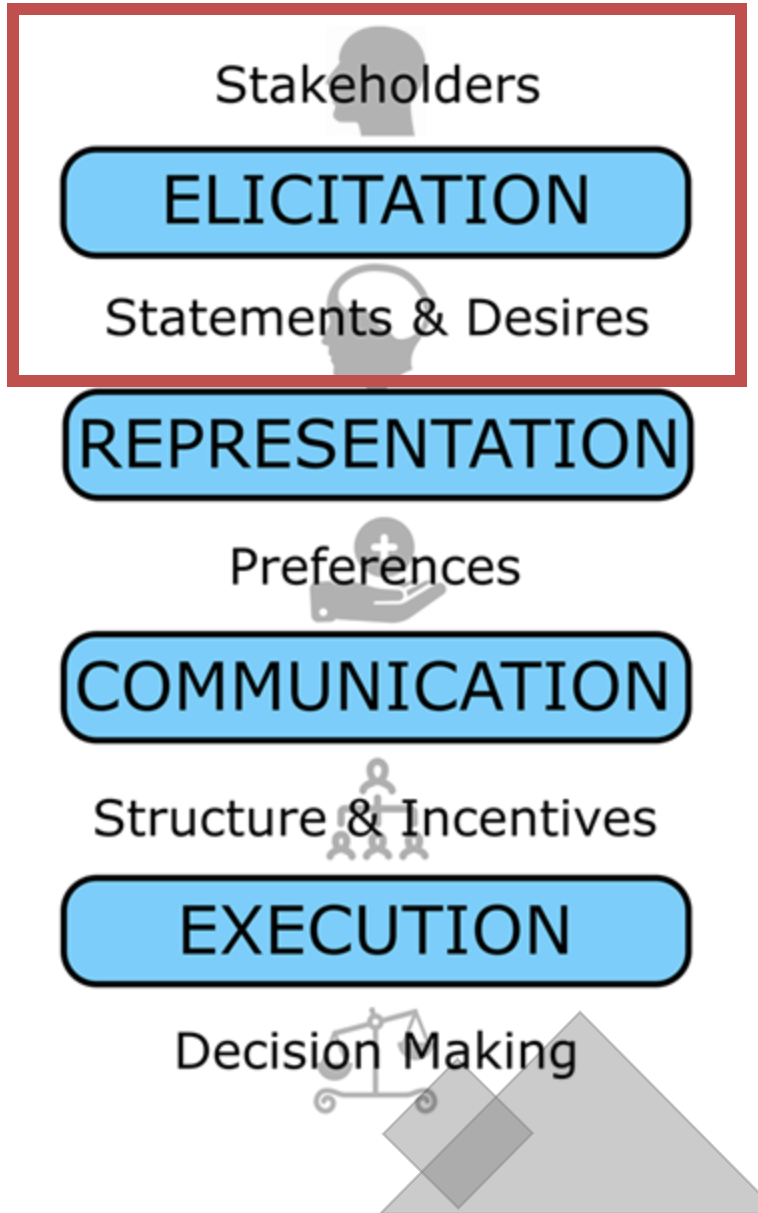

More evidence is needed relating architecting decisions to outcomes

# Decision Making Phases



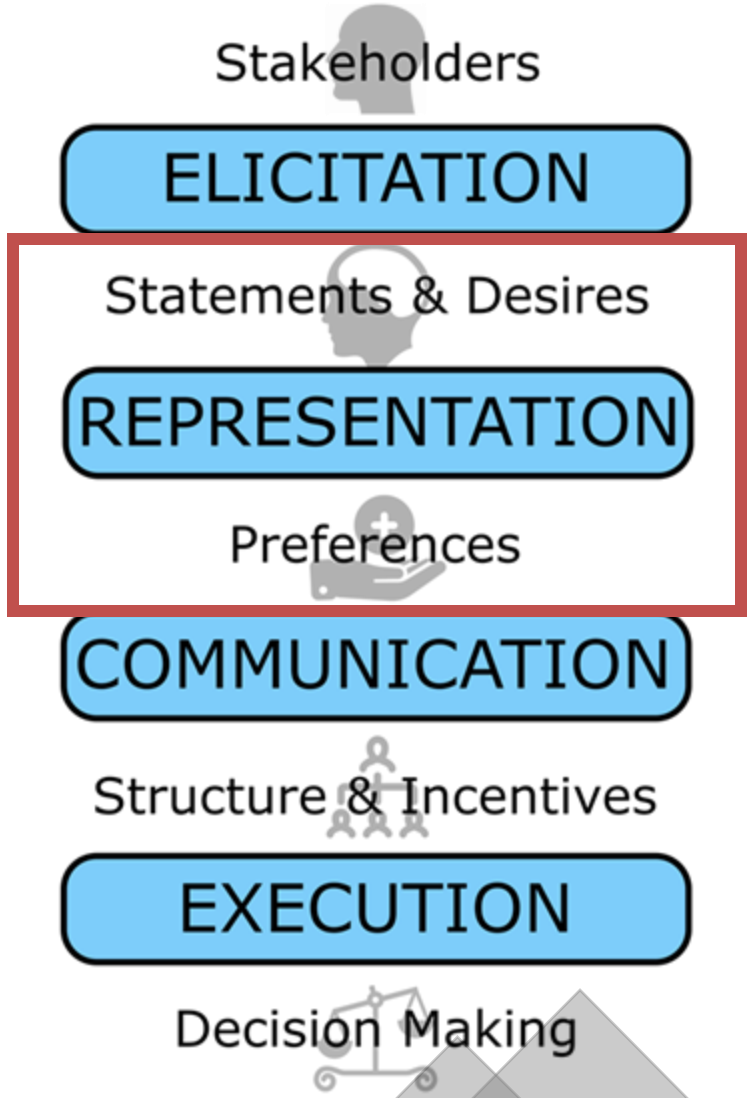
# Decision Making Phases

- Stakeholders often identify –ilities, referred to here as quality attributes (QAs)
- Qas are characteristics that bring value to a stakeholder
  - Adaptability
  - Maintainability
  - Availability
  - Etc.



# Decision Making Phases

- Decision making in Architecting is highly heuristics based
- Rigor in decision making would provide a way to enable evidence-based justification for decisions
- The first step is to improve the representation of decision making inputs, including QAs

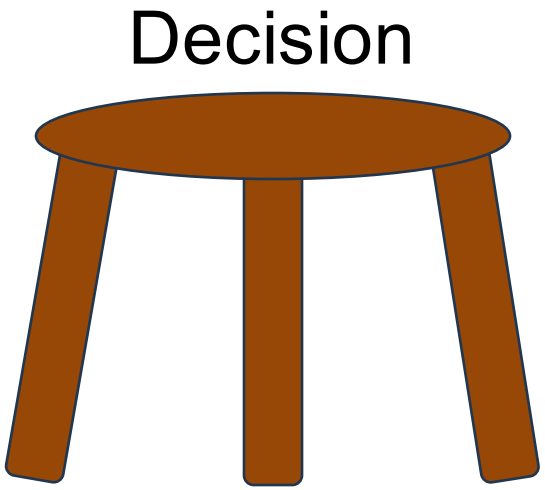


# Research Questions

- What is the current state of representation of decision making inputs?
- What are improvements that can be made to representation of decision making inputs?
- How can we document inputs in a consistent manner?

# Decision Making Inputs

- There are three necessary components of a decision to enable analysis:



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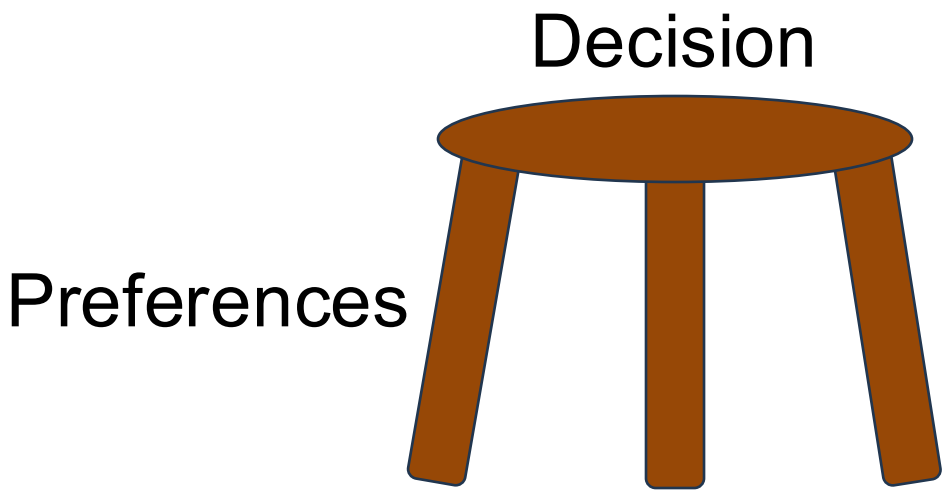

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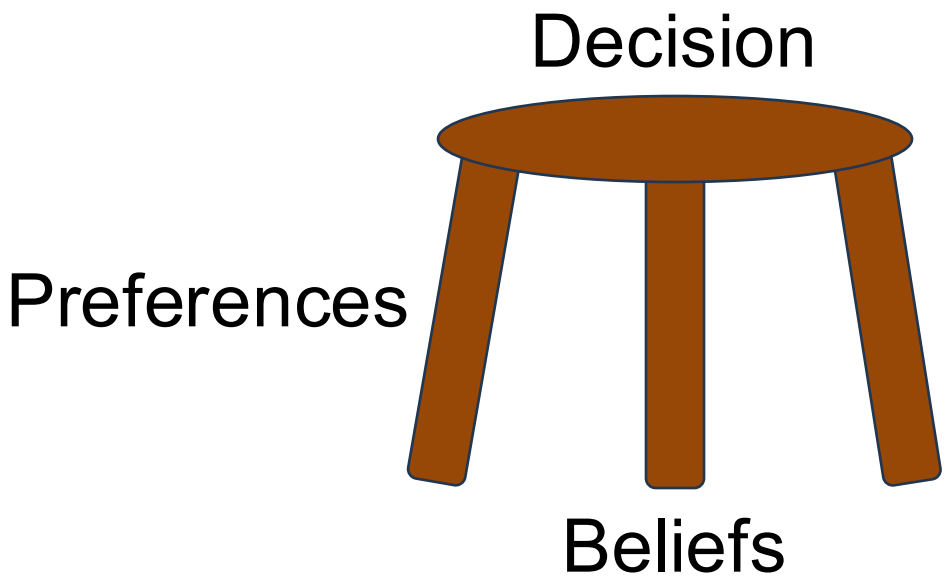

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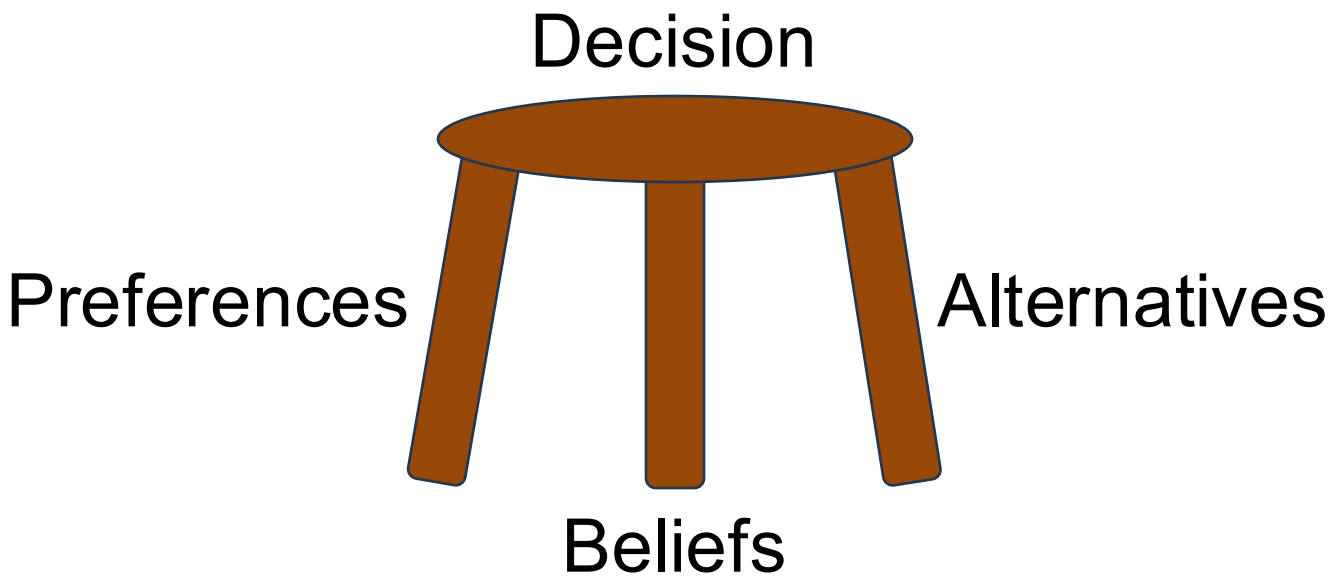
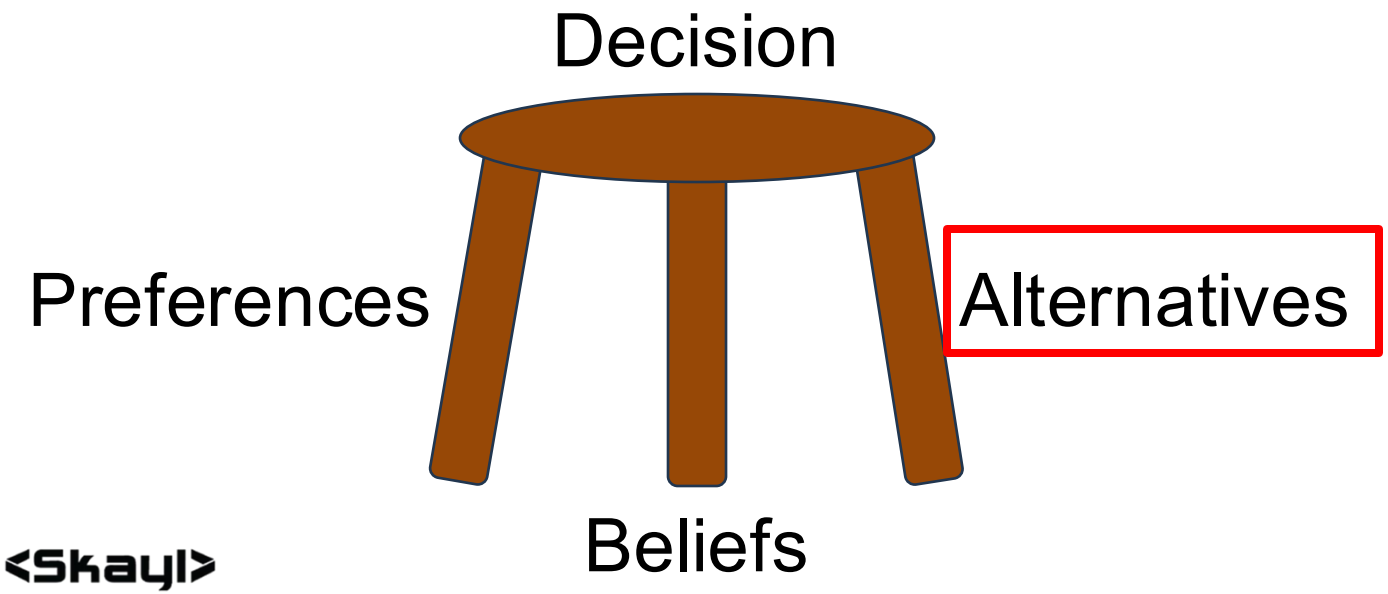


# Decision Making Inputs

- Alternatives are the options the decision maker has to choose from when making a decision.
- Ideally a representation of an alternative would leave no room for multiple interpretations of what the alternative is.



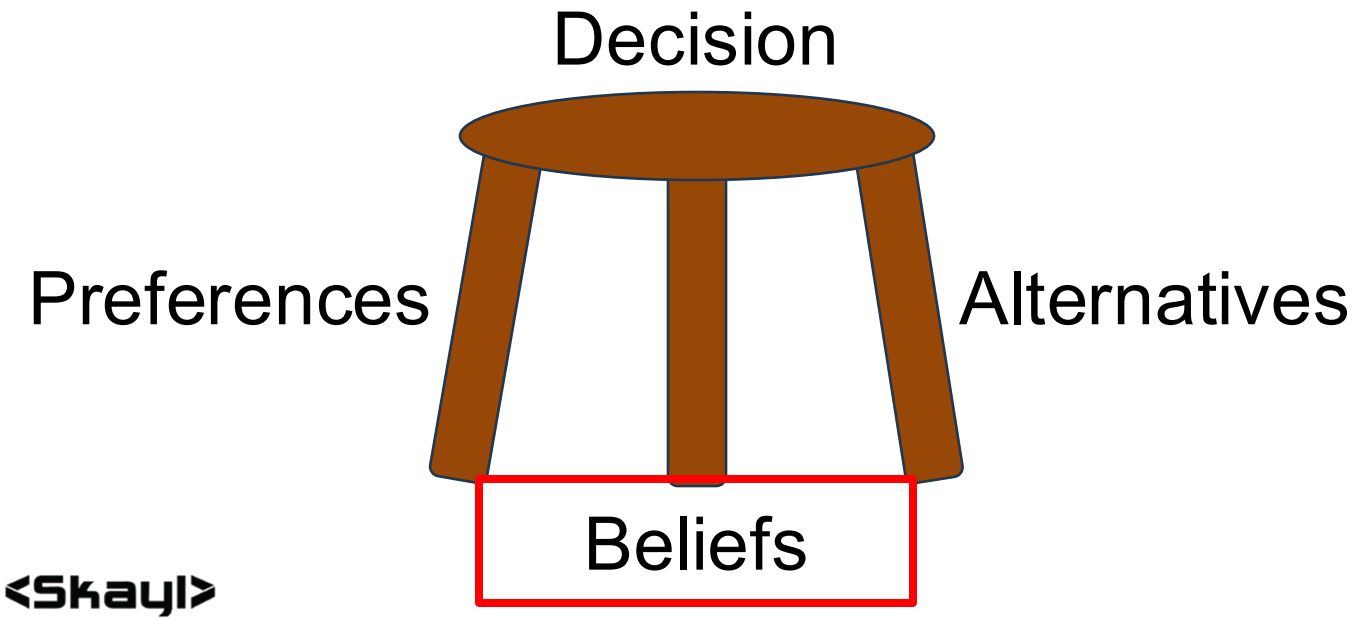
# Alternatives

- Techniques for Representing alternatives are:

| Evaluation | Form | Architecting Example | References |
|---|---|---|---|
| OK | Name Only | Ring Topology | Strandh Tholin, 2021 |
| Good | Qualitative Description | A Ring Topology has edges and nodes | Sormaz et al., 1999 |
| Better | Quantitative Description | A Ring Topology has 2 edges for each node | Scothern, 1991 |

# Making Good Architecting Decisions

- Beliefs are predictions under uncertainty that impact the decision making process.
- Often the most impactful beliefs are those on the outcomes of a decision
- At an architectural level, those outcomes are commonly the QAs



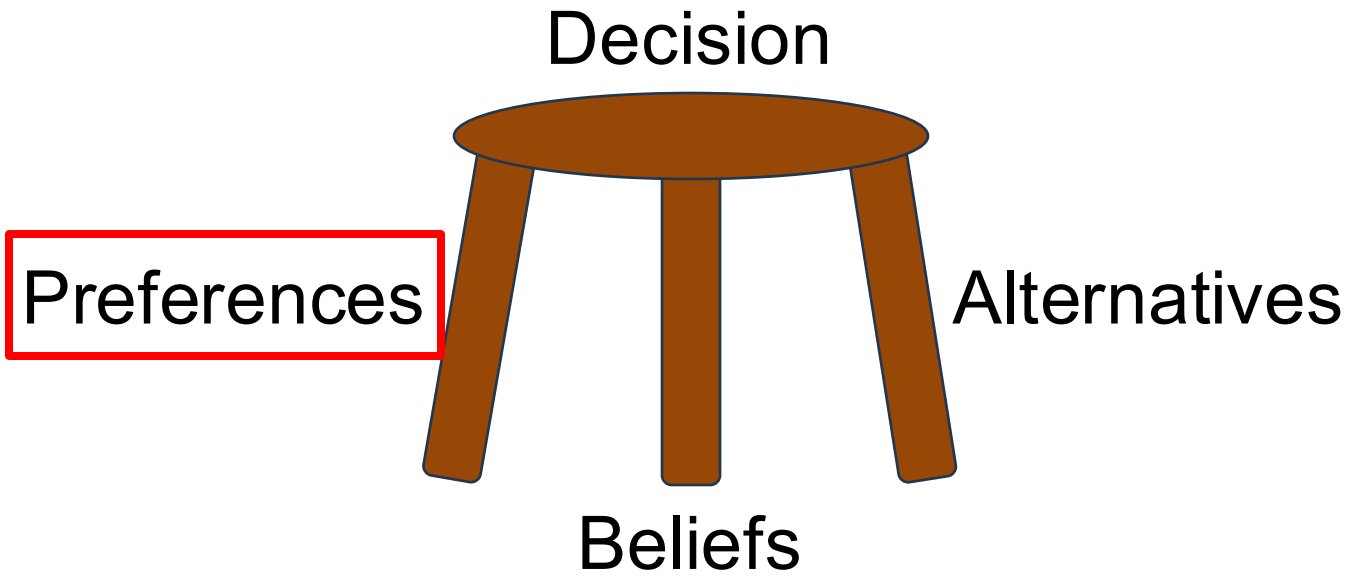
# Making Good Architecting Decisions

- Techniques for Representing alternatives are:

| Evaluation | Form | Architecting Example | References |
|---|---|---|---|
| Poor | Name Only | Modification Cost from Baseline | |
| Poor | Direction | Modification Cost from Baseline is negatively impacted | Ricci et al. 2014 |
| OK | Certain Outcome | Modification Cost from Baseline = $400 Million | Collopy & Hollingsworth 2011, Keller & Collopy 2013 |
| Good | Range of Outcomes | Modification Cost from Baseline between $200 Million and $600 Million | Renou & Schlag 2010, Tuan et al. 2019 |
| Better | Probability Distribution | Modification Cost from Baseline is a triangular probability distribution with a lower of $200 Million, a Mode of $300 Million, and an upper of $600 Million | Pinsky & Karlin 2011, Malak et al. 2015 |

# Making Good Architecting Decisions

- Preferences are the desires concerning the outcomes of the alternative.
- Preferences are subjective, but that doesn't mean they are hidden or ambiguous



# Making Good Architecting Decisions

- Preference Representation Techniques

| Evaluation | Form | Architecting Example | References |
|---|---|---|---|
| Poor | Requirements | Modification Cost from Baseline <= $400M and Accreditation Effort from Baseline <= 5,000 man-hours | Robertson and Roberston, 2012, Hooks, 1994 |
| OK | Rank Order | Outcome A [Modification Cost from Baseline = $300M and Accreditation Effort from Baseline = 4,000 man-hours] is ranked 1st<br>Outcome B [Modification Cost from Baseline = $200M and Accreditation Effort from Baseline = 10,000 man-hours] is ranked 2nd | Tsiporkova and Boeva, 2006 |
| Good | Multiple Objective Function | F(outcomes) = w1*(Modification Cost from Baseline) + w2*(Acredication Effort from Baseline) | Roy, 1971, Hwang and Masud, 2012 |
| Better | Value Model | V(outcomes) = (Modification Cost from Baseline) + $/man-hours*(Acredication Effort from Baseline) | Clerkin and Mesmer, 2018, Lee, Binder, and Paredis, 2014, Collopy and Hollingsworth, 2011 |

# Making Good Architecting Decisions

- Decision making in architecting has the same processes and components as any other decision making process.

- However, there are characteristics of architecting that make the application of decision making techniques challenging.
  - Architectures are not easily measured
  - Architecting informs future decision makers on how to make decisions
  - Architecture time horizon long with extremely high uncertainties
  - Architecture has many stakeholders

# Making Good Architecting Decisions

- All of these characteristics are manageable within the techniques, but additional analyses and elicitation is required to properly define the decision space.

**Architecting needs to move towards better techniques to become more rigorous and intentional in its practice**

# Making Good Architecting Decision Requires Knowledge – How do we build, organize, and maintain this BoK?

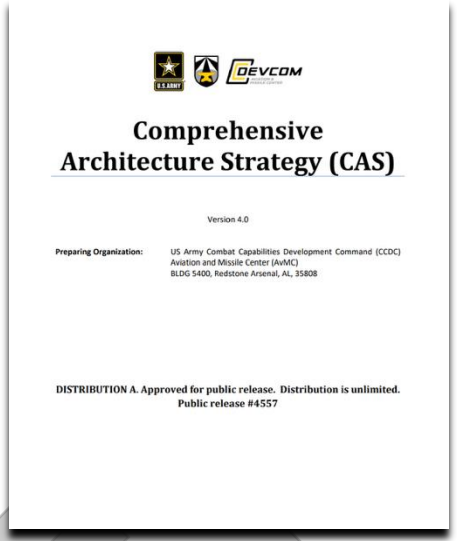
Need Community-Driven Knowledge

- "Material Data Sheets"…. that
  - Stores validated relationships between **mechanisms and QAs**.
  - Incorporates **experiment results, heuristics, and past experiences**.
  - Enables better representation and justification of decisions.
  - BoK as a **SysML-based model** capturing mechanisms, QAs, rules, parameters, operations, and effects.

So where do we get the inputs for decision making?

- Current hype, "Let's just train an AI"
- Comprehensive Architecture Strategy (CAS)

Design vs. Architecture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Comprehensive Architecture Strategy (CAS)

Version 4.0

Preparing Organization: US Army Combat Capabilities Development Command (CCDC) Aviation and Missile Center (AvMC) BLDG 5400, Redstone Arsenal, AL, 35808

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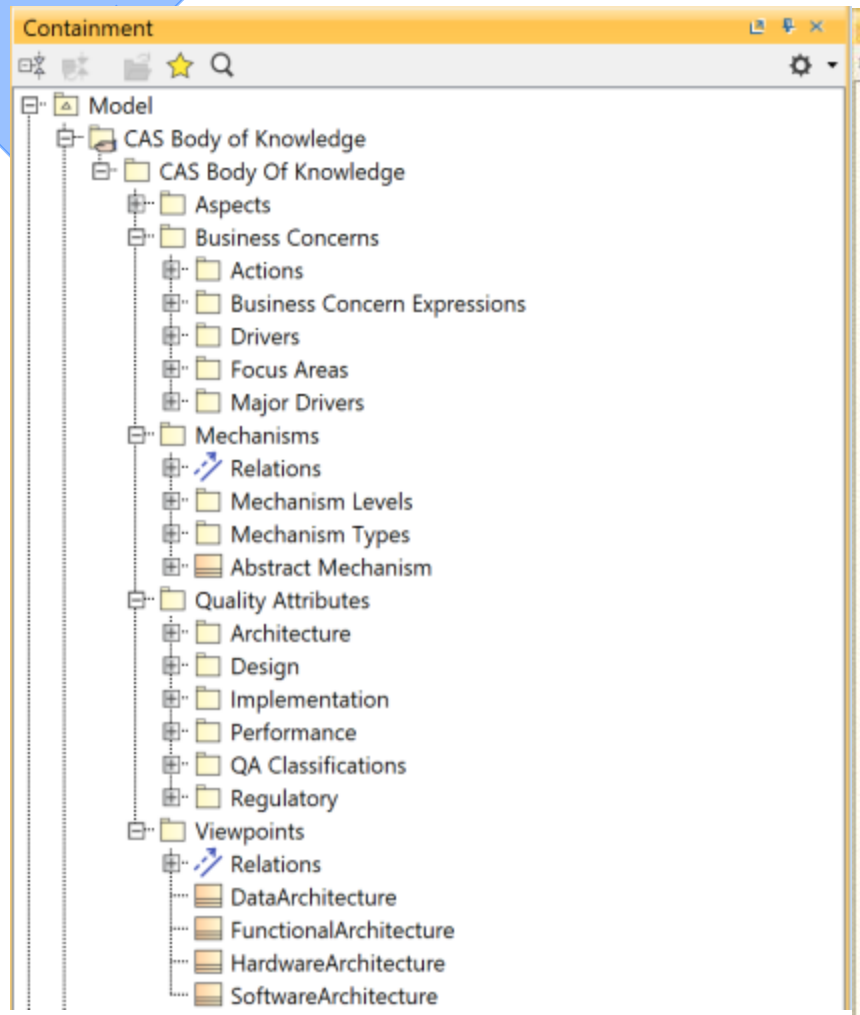
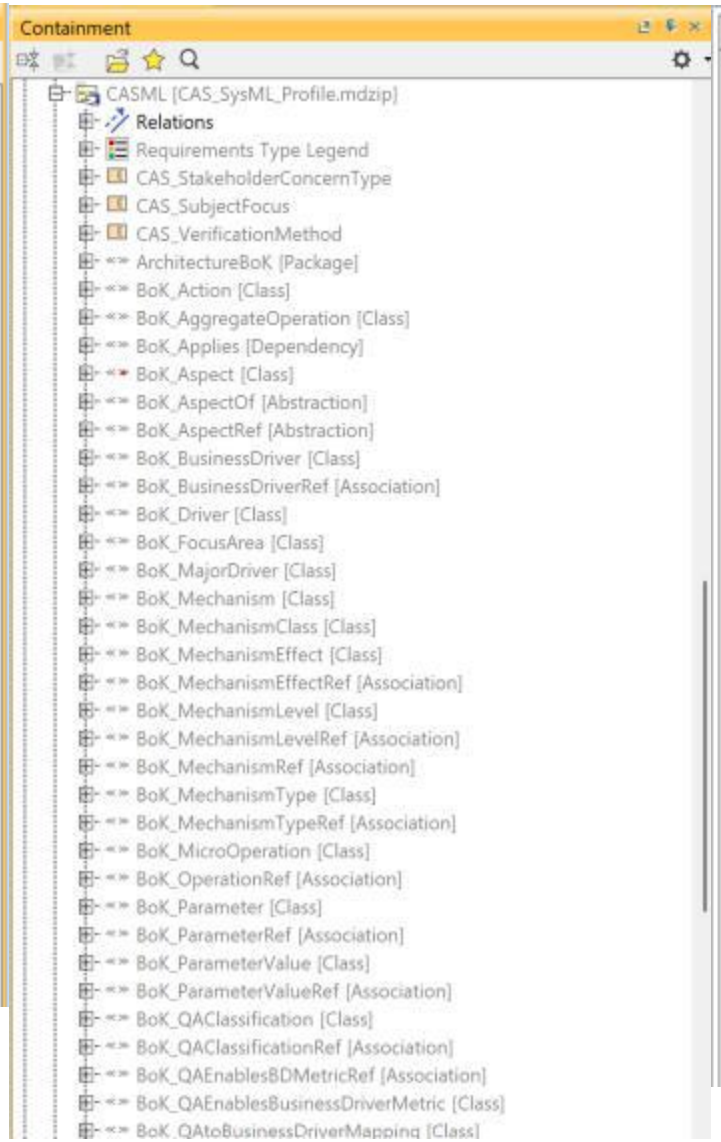
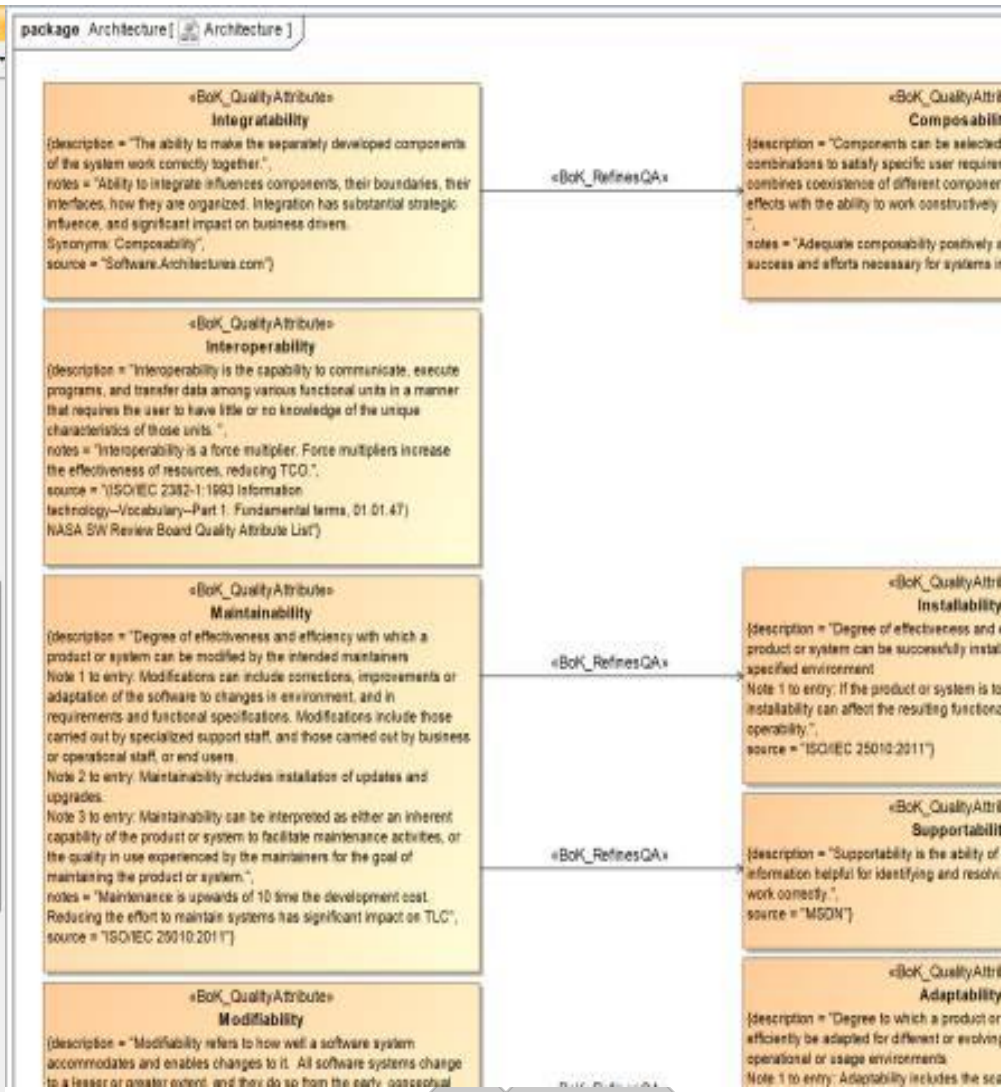
# Organizing the BoK – Comprehensive Architecture Strategy

- The **CAS framework** is the architectural backbone of the BoK. It structures architecture into **three tiers**:
  - **Reference Architecture (RefArch)** – Broad business and regulatory guidance.
  - **Objective Architecture (ObjArch)** – Technology-agnostic and product-line specific.
  - **System Architecture (SysArch)** – System-specific performance and implementation.
- **CAS Elements**
  - **KBDs** (Key Business Drivers): e.g., affordability, interoperability.
  - **KADs** (Key Architecture Drivers): Quality attributes (QAs) critical to the KBDs.
  - **Mechanisms (Parameters, Rules)**: Formal constructs to describe architectural components and decisions.
  - **Relationships and Objective Functions:** measurable relationships between them

# BoK Content - CAS Body of Knowledge

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# Using the BoK
## – It's not linear, relationships are hard to quantify

Even with a simple scenario, the decision space expands quickly

- **High Availability**: Using SOA and redundancy.
- **Security**: Using zero-trust and encryption patterns.
- **Performance**: Through microservices, caching, and API gateways.
- **Communication Pattern:** Distribution via publish-subscribe

Each choice should be assessed for trade-offs (e.g., encryption vs. performance) and documented into the BoK for reuse. Objectively, and fully decomposed, and testable.

# Maintaining the BoK – Experimental Framework

A structured experimental approach for **evaluating architectural mechanisms** against QAs:

- **Define Research Question** – e.g., “Does the Factory Method improve Modifiability?”
- **Develop Framework Model** – Define mechanisms, rules, and parameters.
- **Simulation Development** – Use Monte Carlo, discrete-event, or agent-based models.
- **Analyze and Refine** – Collect data, perform sensitivity and statistical analysis.

# Organizing the BoK – Keep the one thing, the one thing

Quality Attribute Decomposition

- Characteristics of Qualities - shared across the qualities

Mechanism Decomposition

- Quantify the ‘effect’ a mechanism has on a characteristic
- Distance between effects - this is the architecturing maneuver room

Recommendations:

- **Standardizing submission** to the BoK.
- Consider **“super patterns”.** Flexible architectural mechanisms that can emulate others (e.g., a mesh topology mimicking ring or hub topologies).
- Use **vector space models** to relate mechanisms via similarity metrics.

# What's Next

- The BoK, backed by CAS, enables:
  - More **predictive and justifiable architectural decisions**.
  - A **growing, shared repository** of mechanisms and their impact on QAs.
  - A shift toward **data-supported, experimental architecture development**.

- What can you do?
  - BoK community engagement,
  - Further research into abstractions,
  - Tooling to support BoK curation and use.

# Bringing it together

- In order to move architecting from heuristics to principles, we need to establish our knowledge in a consistent and rigorous manner.
- Decisions are the core element in architecting
- There are many layers of methods that can be adopted to improve decision making
- Enabling justifiable, evidence-based decisions is key to grounding architecting
- The first step is representing decision inputs in a usable and meaningful form
- The second step is leveraging community collected and validated knowledge to enable informed and justified decisions.