SYSTEMS ENGINEERING RESEARCH CENTER

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Improving and Assessing Architectures and Architecture Decision Making

WRT 10748

Office of the Assistant Secretary of Defense for Research and Engineering

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The Research Team

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Research Team








Motivation and Research Goal

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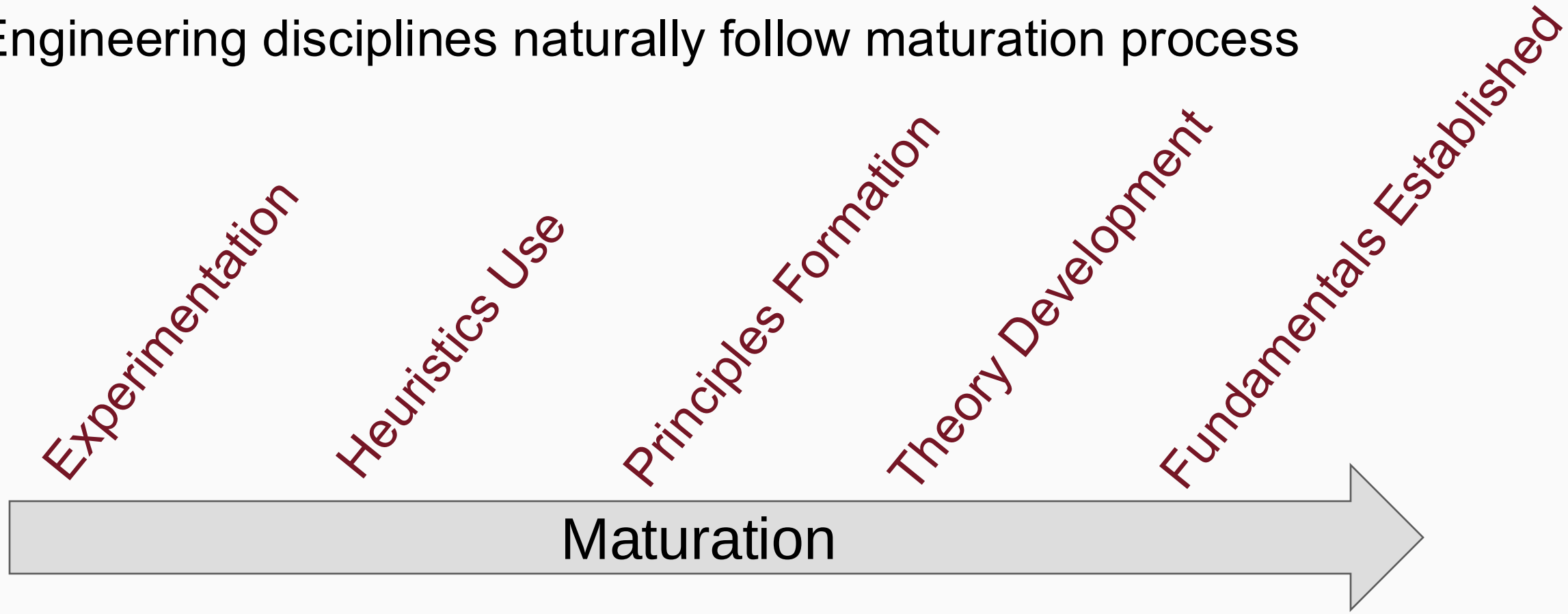
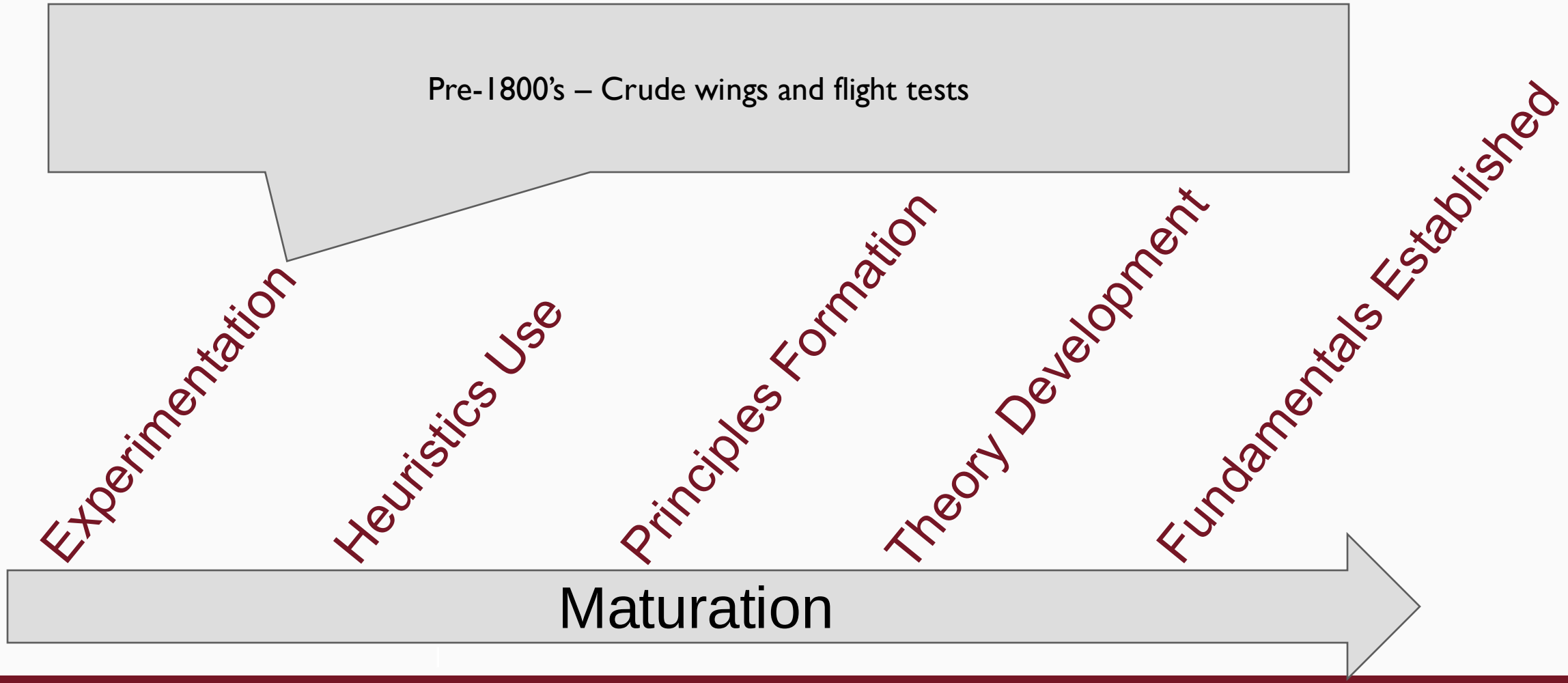
Motivation

- Engineering disciplines naturally follow maturation process



Motivation

- Aerospace Engineering Example



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Motivation

- Aerospace Engineering Example

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

Maturation

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

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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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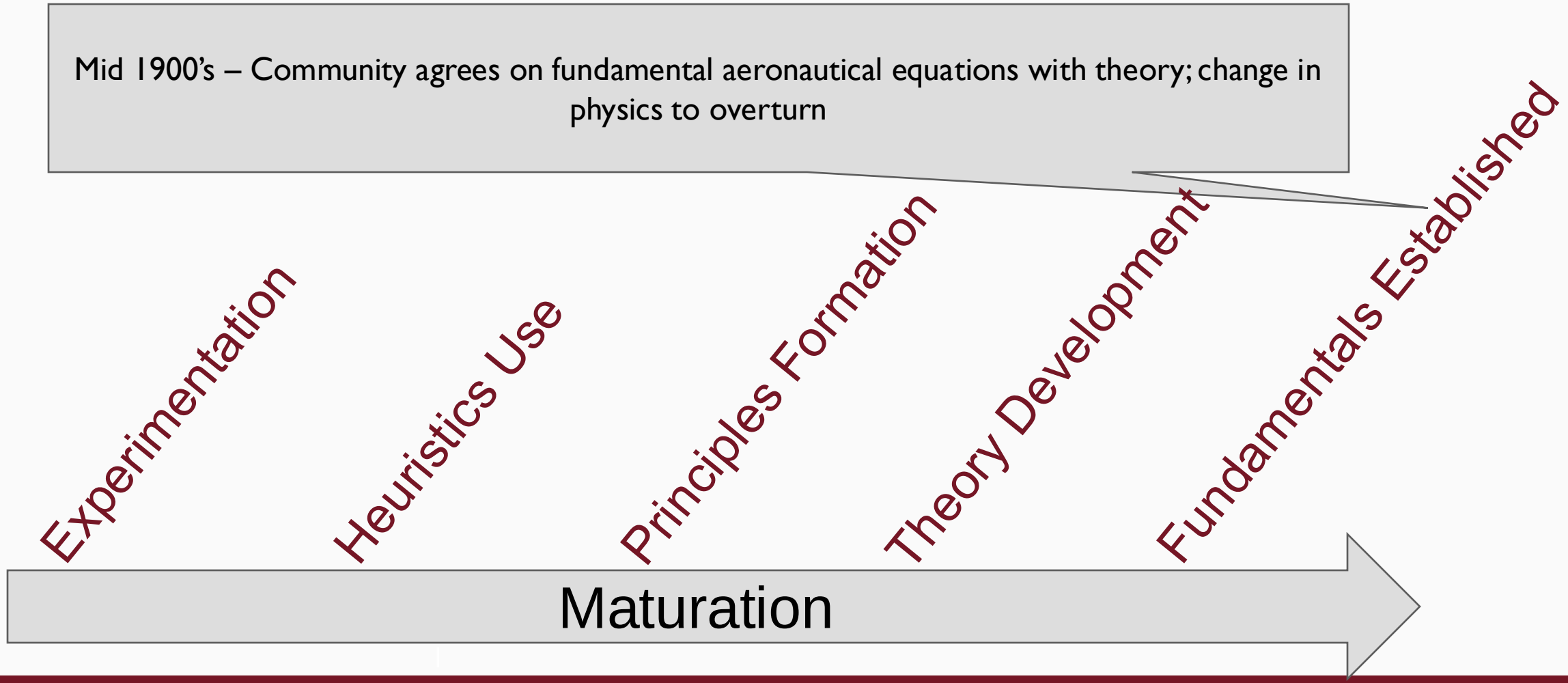
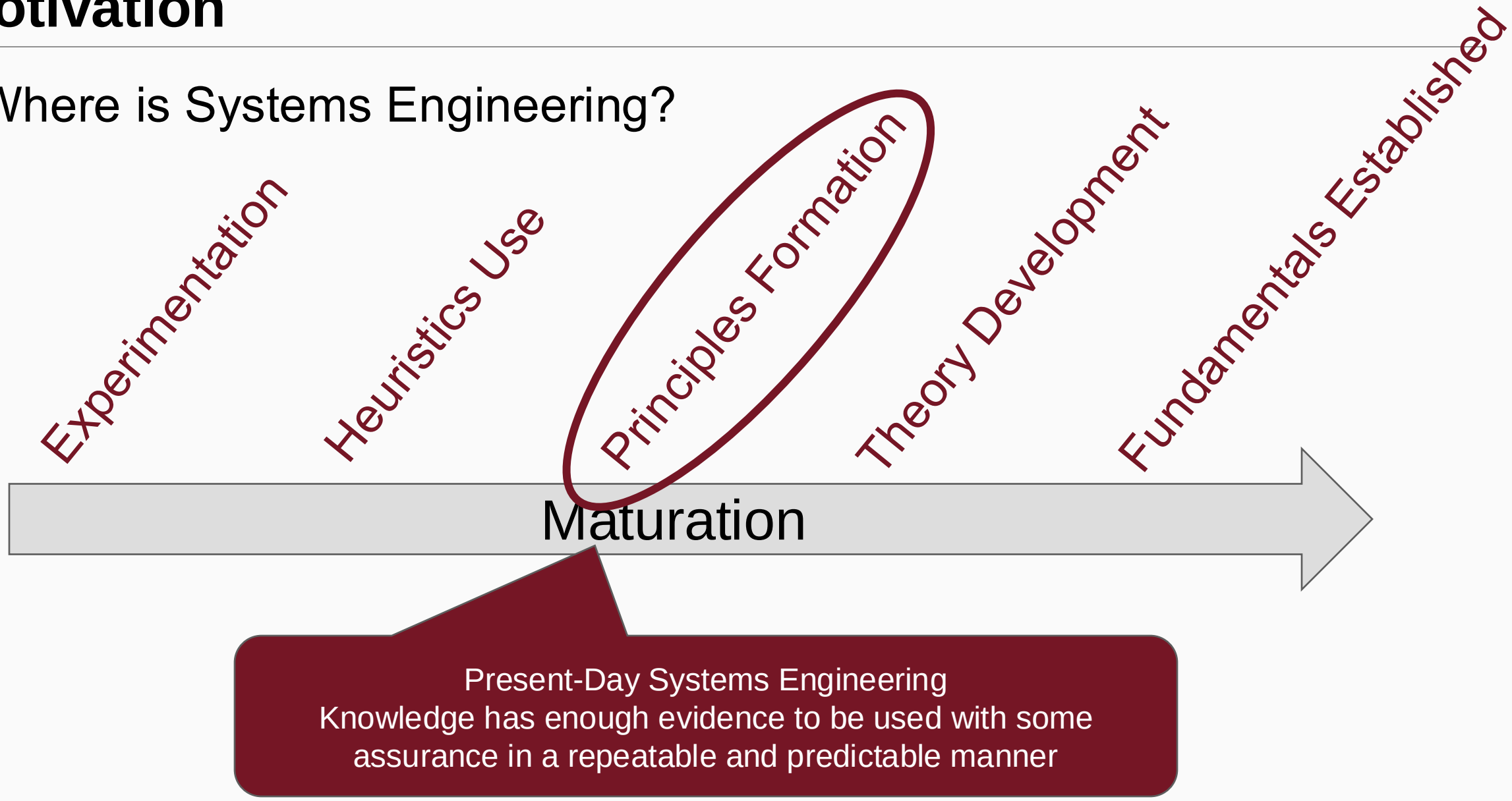
Motivation

- Aerospace Engineering Example



Motivation

- Where is Systems Engineering?



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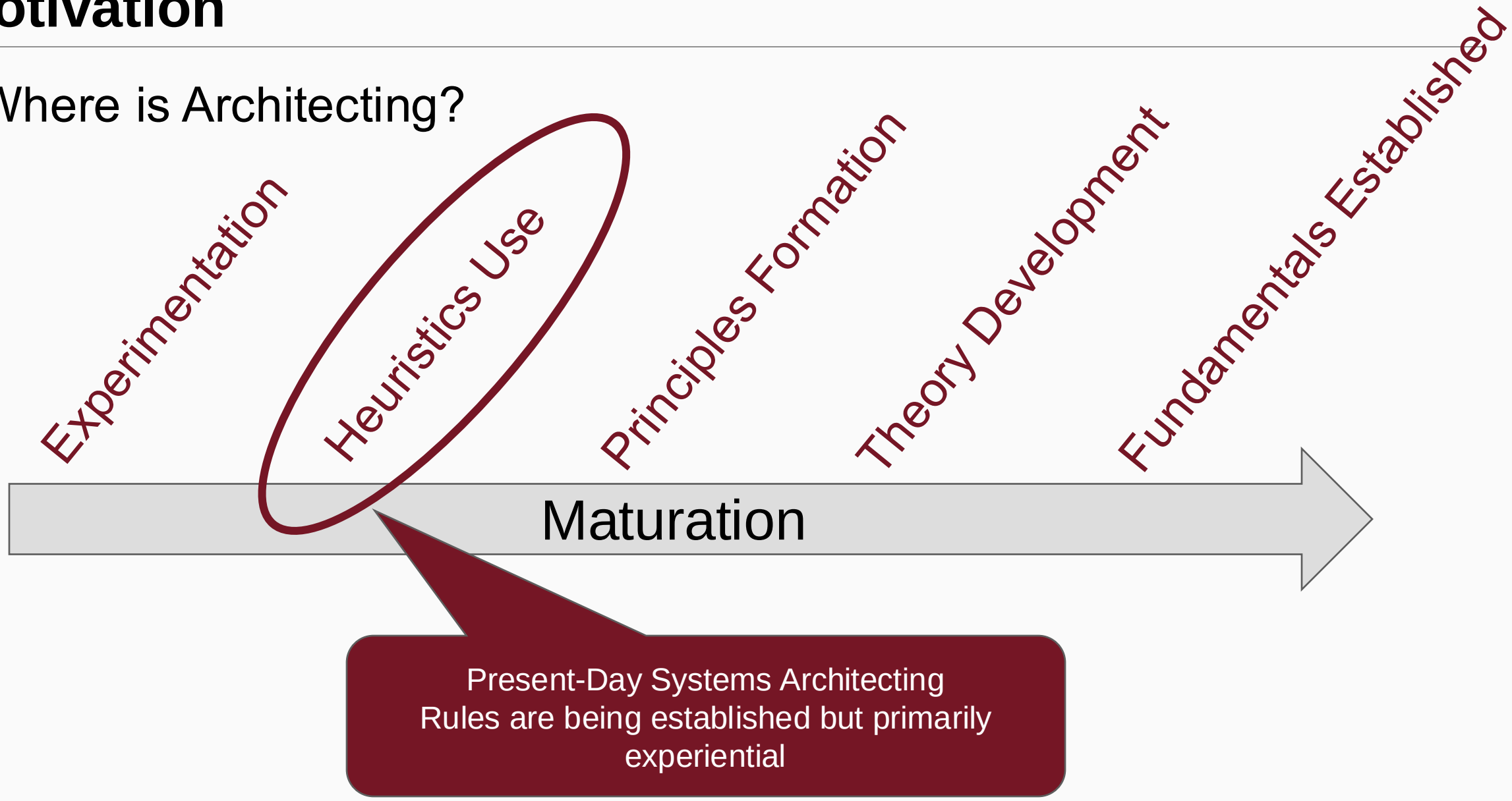
Motivation

- Where is Architecting?



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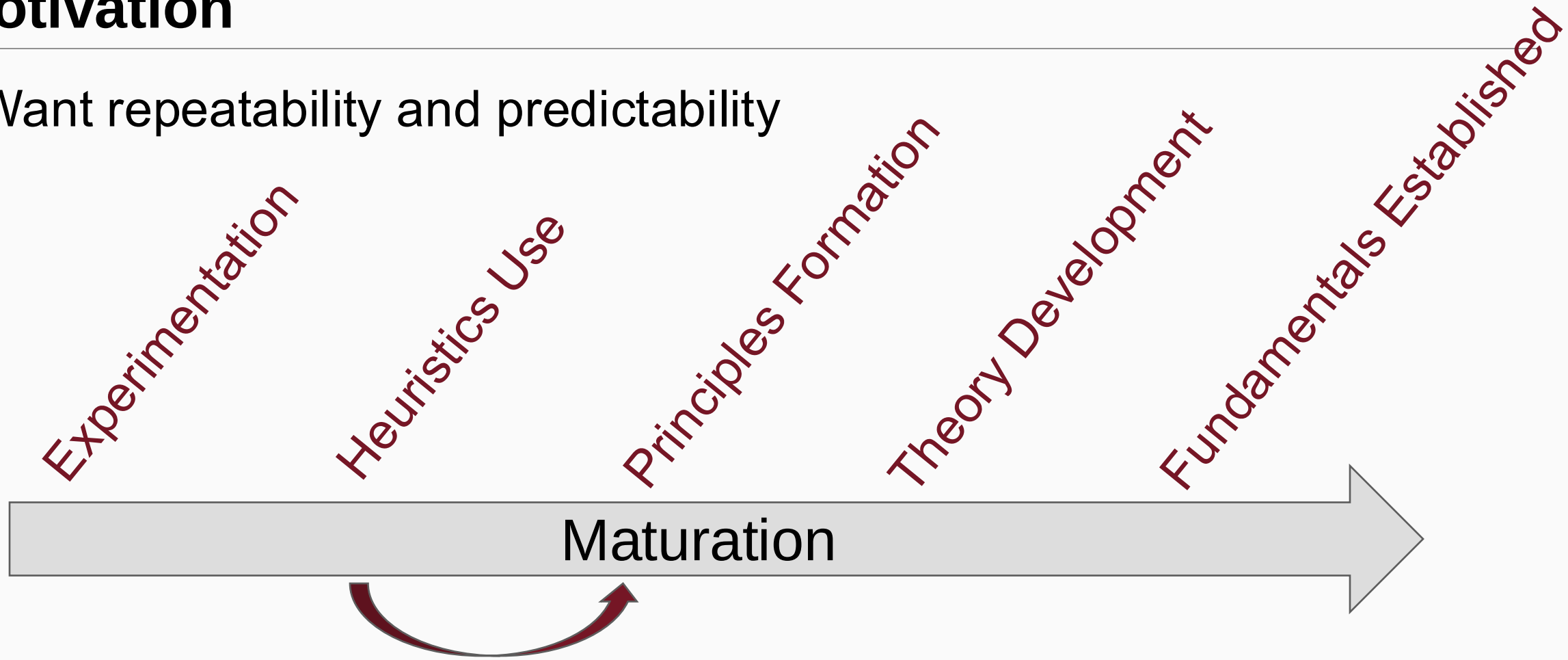
Motivation

- Want repeatability and predictability



More evidence is needed relating architecting decisions to outcomes

Motivation

- Architecting is broad, where to start?
  - Differentiating Architecting from Designing
  - Understanding how architectures are assessed
  - Process of decision making for architects
  - Representing beliefs held by architects
  - Training architects

Research Project

- Base Task
  - Architecting and Designing – Decision Differences

Sub Task 1	Sub Task 2
Systematic Literature Study of Architecting and Designing Decisions	Relationship between Architecting and Game Theory

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Sub Task 1 Work Break Down

Systematic Literature Study of Architecting and Designing Decisions

I. Identify relevant key words for exploring decision types within architecting and designing
II. Identify key journals and conferences
III. Identify exclusion criteria
IV. Identify concepts/data to elicit from literature
V. Form coding system
VI. Form database of concepts and codes
VII. Analyze concepts within database
VIII. Compare and contrast results between architecting and designing
IX. If a lack of literature sources is determined then surveys and/or interviews of practitioners will be conducted

Sub Task 2 Work Break Down

Relationship between Architecting and Game Theory

I. Identify key decision concepts of architecting, leveraging systematic literature review and Army SMEs
II. Identify key game theoretic concepts, along with related assumptions
III. Identify potential similarities between architecting and game theoretic concepts
IV. Verify relationships using assumptions/requirements established within game theory
V. Form multiple cases for exploration of relationships
VI. Detail evidence associated with each relationship

Sub Task 1: Literature Study of Architecting and Designing Decisions

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Differences And Similarities Between Architecting and Designing

- Compared to designing, system architecting is a newer, still evolving concept
- A previous study on the differences between systems engineering and architecting [1] found no clear consensus.
  - Architecting and designing may also have no clear consensus.
- Without a clear understanding of the similarities and differences between architecting and designing, it may be difficult to:
  - Appropriately assign work
  - Identify process inefficiencies
  - Reduce project churn
  - Etc.

[1] Emes, M. R., Bryant, P. A., Wilkinson, M. K., King, P., James, A. M., & Arnold, S. (2012). Interpreting "systems architecting". *Systems engineering*, *15*(4), 369-395.

Objective

- What are the stated, perceived differences and similarities between systems designing and systems architecting in the academic literature?

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Methodology

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Overview of Content Analysis

Source Identification and Data Extraction

Google Scholar and RPYS

Search Terms

e.g., design and architecture in systems engineering; system design versus system architecture

87 Sources Collected

Inclusion Criteria

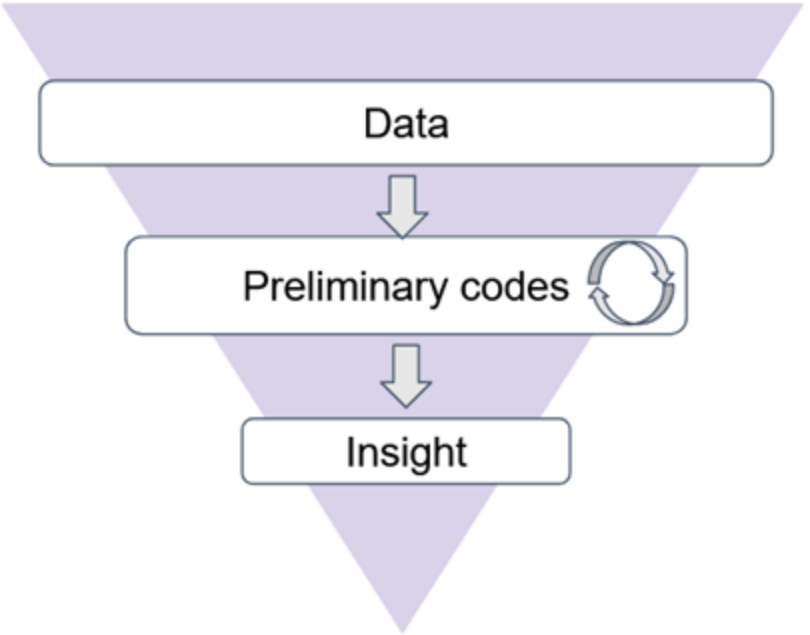
a. Published in English

b. Compared or described architecting, design, architect, or designer

Data

Direct Comparisons: 37/87
Indirect Comparisons: 5/87
Only defined one: 27/87

Inductive Coding: "Data speaks"



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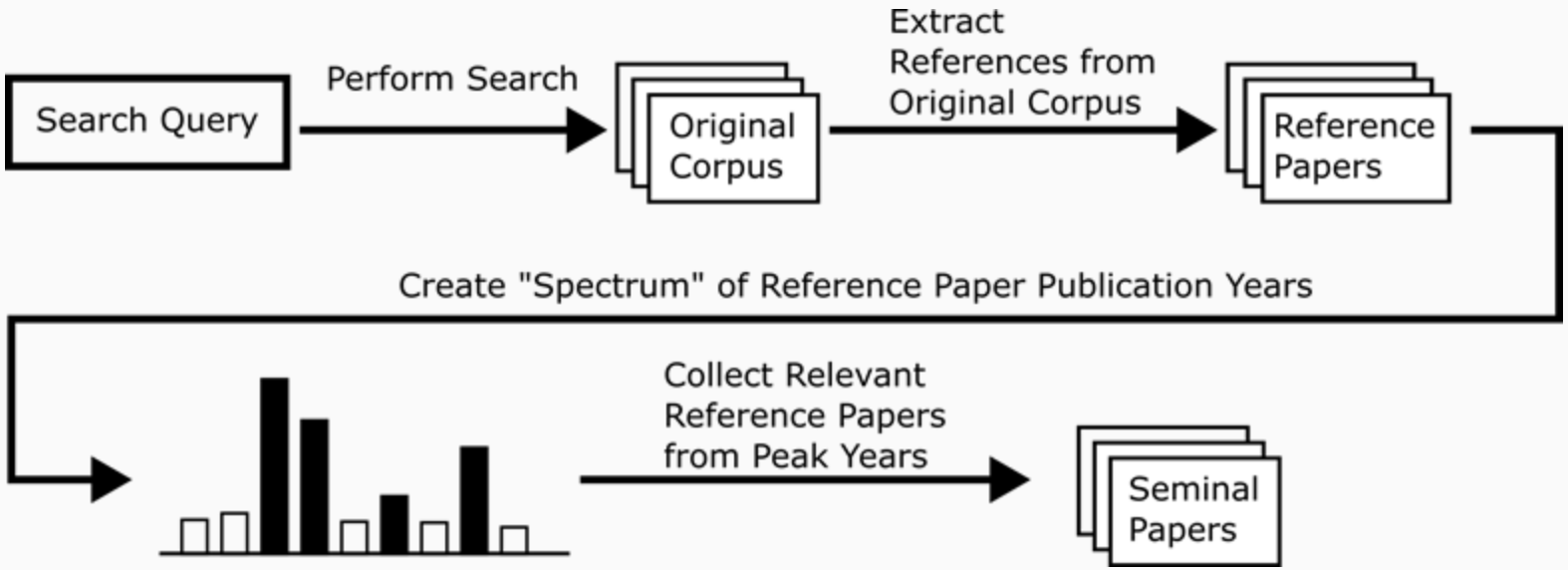
RPYS

- Reference Publication Year Spectroscopy (RPYS) is a method for identifying seminal works in a field
- Used with Google Scholar to balance recent works with older, seminal ones



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Search Strings

GOAL: Coverage for architecting and designing comparisons from literature within both domains AND coverage for role comparisons.

STRATEGY: Two repositories can reduce any gaps in coverage in either. Diversifying search strings can identify different sub-communities within the domains of architecting and design.

Google Scholar

designing and architecting systems engineering

systems engineering roles

system design versus system architecture

system design versus system architecture "systems engineering"

designing vs architecting

architects vs designers systems engineering

architects vs designers "systems engineering roles"

Army System Engineering Handbook

"differences between architecture and design" systems

"architecture versus design" systems

"architecture differs from design" systems

Semantic Scholar RPYS

architecting in systems engineering

design and architecture in systems engineering

design in systems engineering

product design process

product design process in engineering

design process in engineering

architecting process in engineering

differences between design and architecting

system design versus architecting

system architect role

design role and task

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Coding Methodology

- To develop more suitable codes, we used an inductive coding process.
- Uses the collected data to develop codes, rather than deductive coding, which develops codes a priori. [2]
- Develop codes most relevant to the collected data, rather than relying on preconceptions. [3]

[2] Potter, W. J., & Levine-Donnerstein, D. (1999). Rethinking validity and reliability in content analysis. Journal of Applied Communication Research, 27(3), 258–284. https://doi.org/10.1080/00909889909365539
[3] Linneberg, M., & Korsgaard, S. (2019). Coding qualitative data: A synthesis guiding the novice. Qualitative Research Journal. https://doi.org/10.1108/QRJ-12-2018-0012

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Major Codes and Definitions

- Timing
  - When designing and architecting occur relative to each other
- Information
  - The flow of information from designing or architecting to the other
- Subset
  - The shared elements (activities, tasks) between designing and architecting
- Responsibilities
  - The assignment of responsibility among teams and individuals for designing and/or architecting
- Granularity
  - How broad or focused the concerns of designing and architecting are
- Misfit
  - Any quote that does not fall into the preceding codes

Timing Subcodes and Definitions

Timing: When designing and architecting occur relative to each other

- Sequential, architecting first
  - Architecting occurs first, followed by designing
- Sequential, design first
  - Designing occurs first, followed by architecting
- Simultaneous
  - Both architecting and designing occur simultaneously
- Iterative
  - Architecting and designing occur in an iterative loop
- Separate phases
  - Architecting and designing occur separately in time, but in an unspecified order

Information Subcodes and Definitions

Information: The flow of information from designing or architecting to the other.

- Architecture informs design
  - Information from architecting flows to designing
- Design informs architecture
  - The information from designing flows to architecting
- Both inform each other
  - Information from both processes flow into the other
- Isolated
  - Information from either process does not cross into the other

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Subset Subcodes and Definitions

Subset: The shared elements (activities, tasks) between designing and architecting.

- Identical
  - Designing and architecting have all the same elements
- Architecting within design
  - The elements of architecting are contained within designing
- Design within architecting
  - The elements of designing are contained within architecting
- Both subsets of SE or a larger process
  - The activities of designing and architecting are contained within SE or another overarching process
- Partial overlap
  - Some elements of designing and architecting are shared, but not all

Responsibilities Subcodes and Definitions

Responsibilities: The assignment of responsibility among teams and individuals for designing and/or architecting

- Architects coordinate design
  - Architects become responsible for coordinating designing as the engineering effort becomes more complicated
- Same team/individual
  - Architecting and Designing are performed by the same team or individual
- Different teams/individual
  - Architecting and Designing are performed by separate teams or individual

Granularity Subcodes and Definitions

Granularity: How broad or focused the concerns of designing and architecting are.

- Architecting Overarching/Designing Detailed
  - The concerns of architecting are broad and the concerns of designing are more focused
- Designing Overarching/Architecting Detailed
  - The concerns of designing are broad and the concerns of architecting are more focused
- Both similar breadth of focus
  - Both architecting and designing have comparable breadth of concerns

Results

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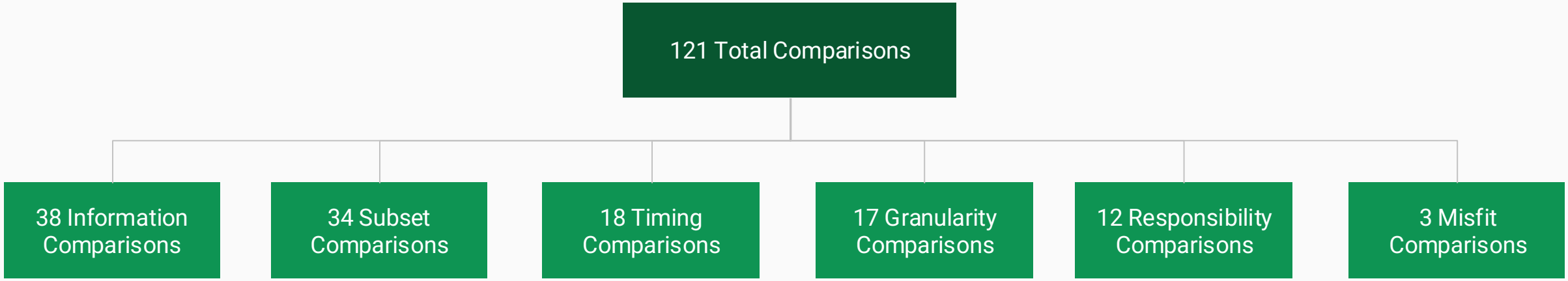
Final Coding Summary



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Inter-Rater Reliability

Inter-Rater Reliability	
Type	**Kappa (κ)** ± 95% Confidence Interval
Major Codes	0.544 ± 0.090
Information	0.789 ± 0.119
Subset	0.848 ± 0.109
Granularity	0.805 ± 0.152
Timing	0.713 ± 0.192
Responsibilities	0.760 ± 0.206
Misfit	0.742 ± 0.354

Inter-Rater Reliability Scale	
Value of κ	**Strength of Agreement**
< 0.20	*Slight*
0.21 - 0.40	*Fair*
0.41 - 0.60	*Moderate*
0.61 - 0.80	*Substantial*
> 0.80	*Almost perfect*

Note: the rarity of some of the major codes, especially Misfit, broaden the confidence intervals substantially. The overall reliability is lower than the individual major codes due to mismatches in the number of codes assigned to each quote by coders.

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Major Code Analysis

- Comparisons focus on Information (38) and Subset (34) comparisons.
- Timing (18) and Granularity (17) are mentioned about half as often as Information and Subset.
- Responsibilities (12) is the least mentioned comparison outside of Misfit (3).

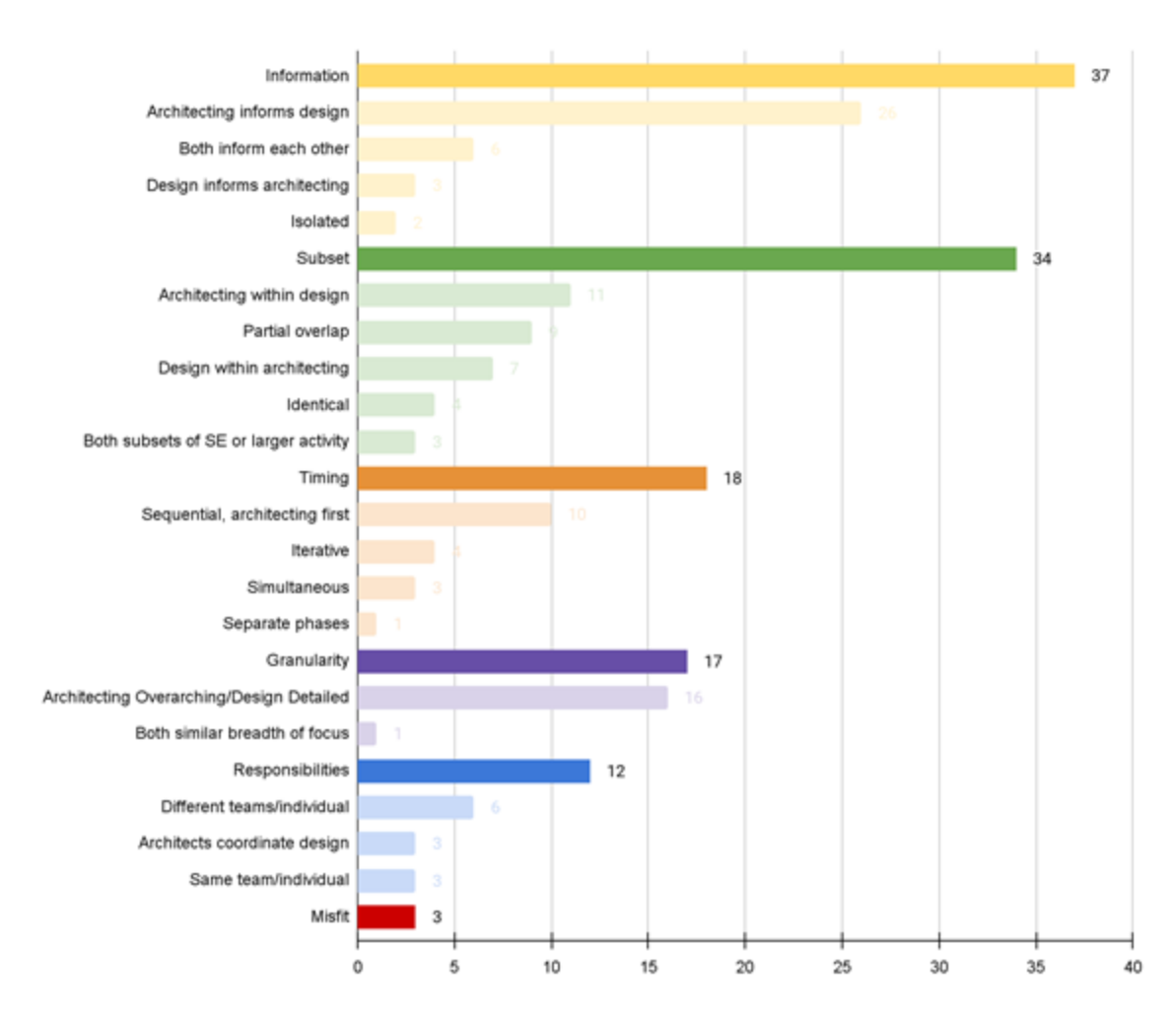

Figure 1: *Frequency of Codes*

Information Analysis

- Information comparisons were the most common.
- Most information comparisons (26) established the flow of information to be from architecting to design.

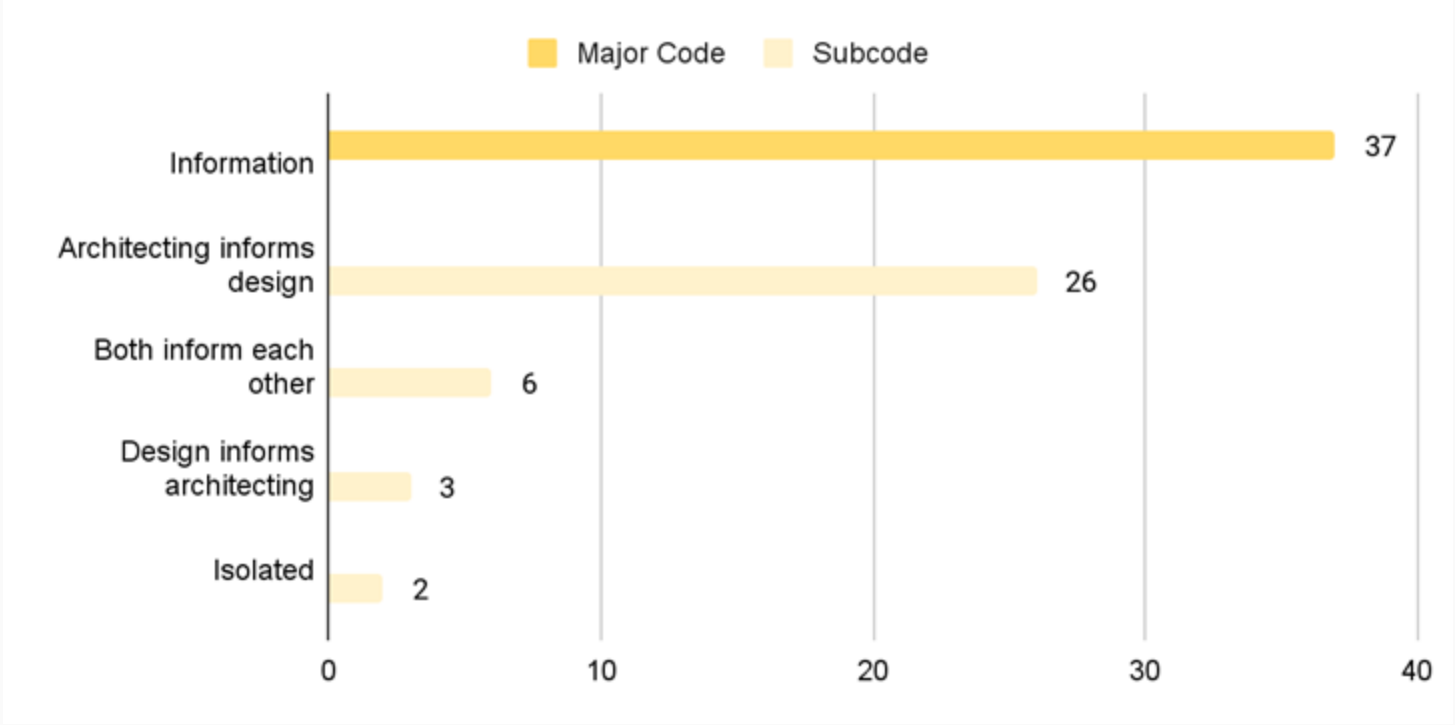

Figure 2: *Information subcode distribution*

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Subset Analysis

- Little consensus of how architecting and designing overlap.
- The relationship between the activities of architecting and design is a commonly mentioned difference.
- Architecting is often within system designing, and component designing is often within architecting

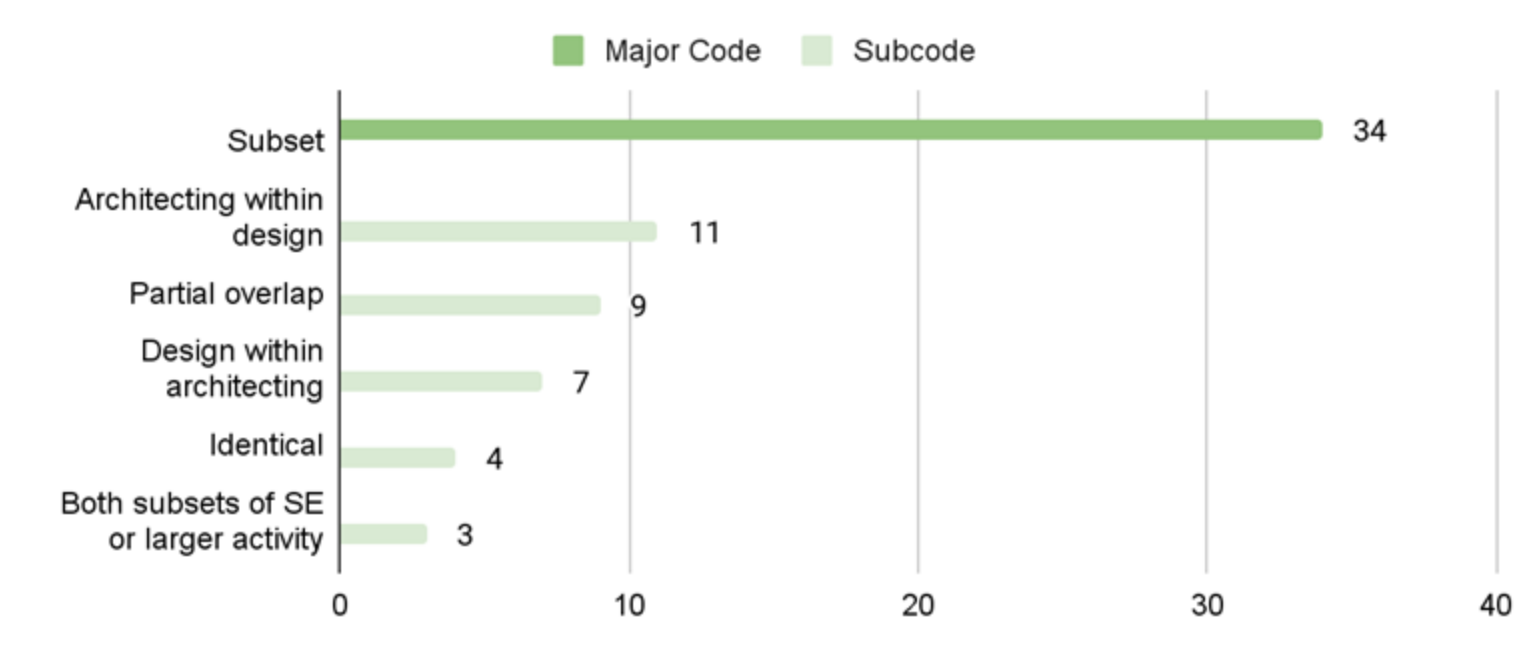

Figure 3: *Subset subcode distribution*

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Timing Analysis

- Slight skew of architecting being completed before design work (10).
- Overlapping (iterative and simultaneous) make up almost as many comparisons (7).

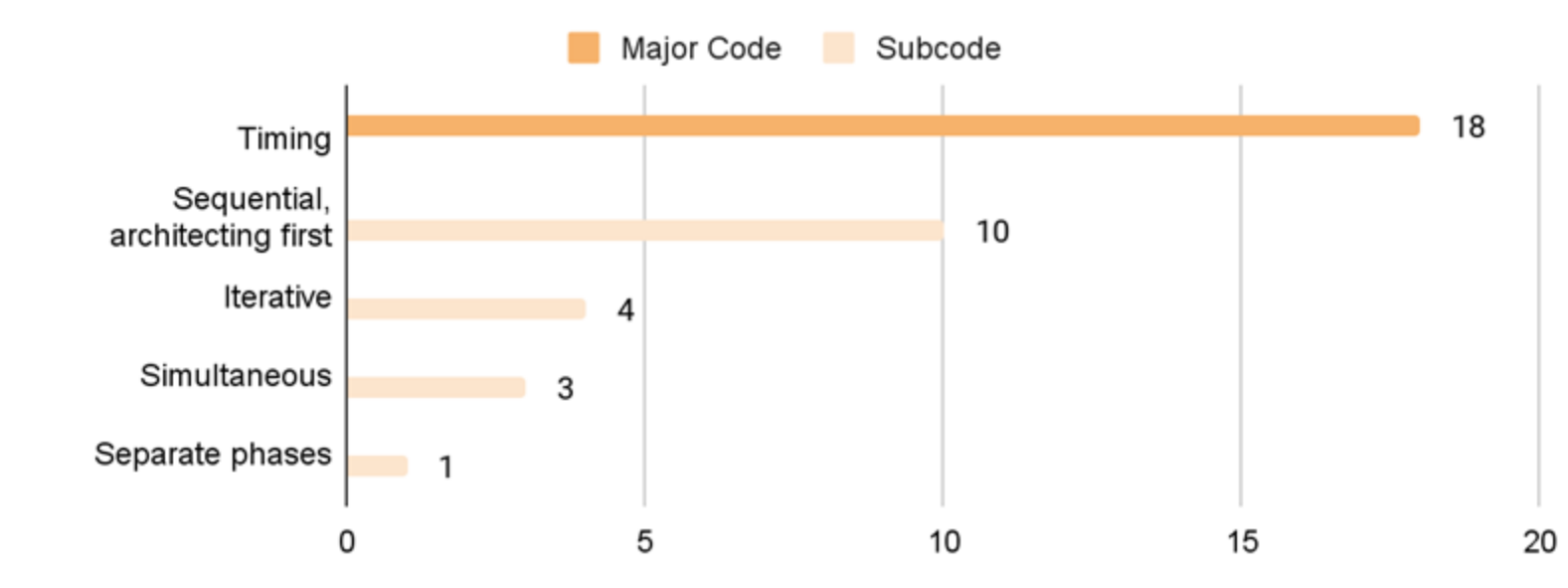

Figure 4: *Timing subcode distribution*

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Granularity Analysis

- Architecting is perceived to be a high level process while design is perceived as a lower level process.
- Only 1 example compared both as having similar levels of granularity while no examples suggested design is high level and architecting is low level.

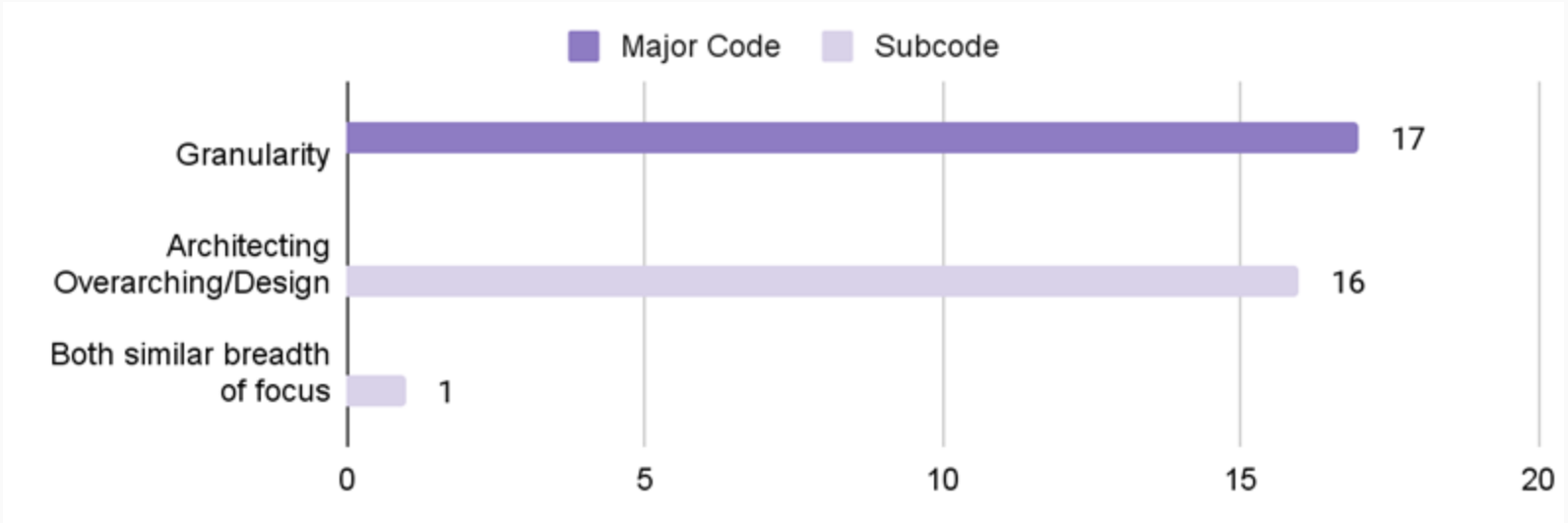

Figure 5: *Granularity subcode distribution*

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Responsibilities Analysis

- Contradictions around whether architecting and design are completed by the same people.
- Overall few responsibility comparisons.

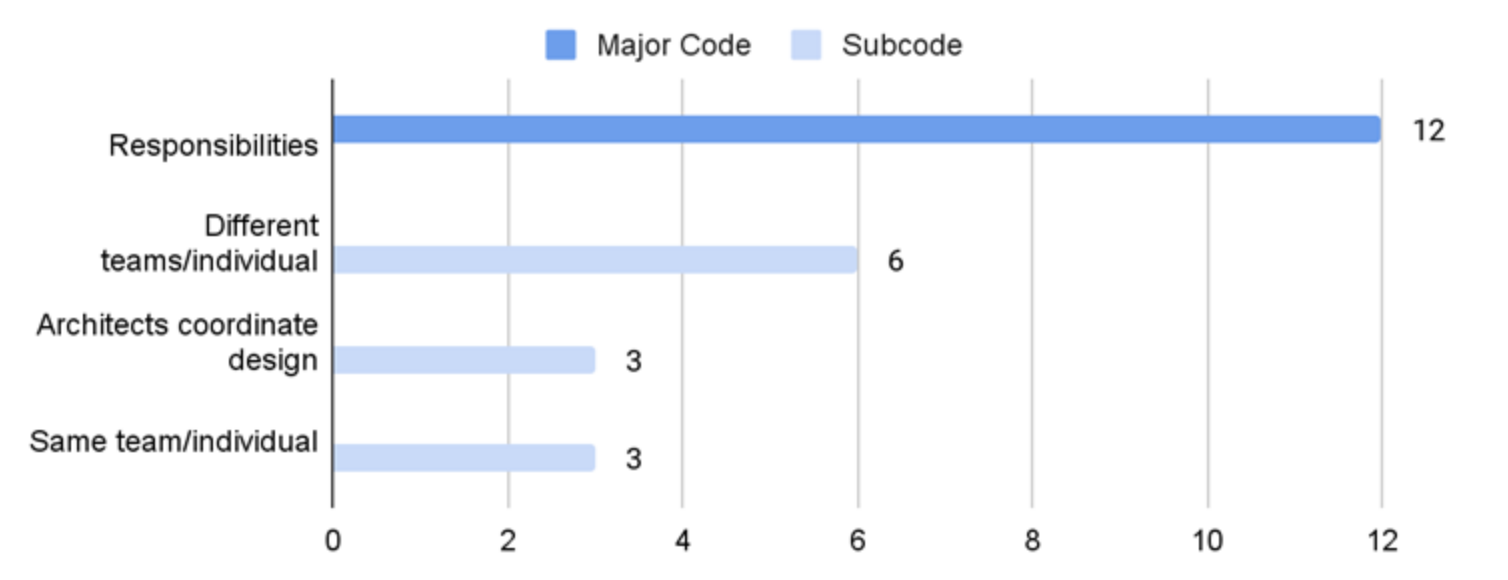

Figure 6: *Responsibility subcode distribution*

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Misfit Quotes

Quote 1	Quote 2	Quote 3
"Looking at the above, the focus of architecture work is fitness for purpose, while that of design is optimization." [4]	“One of the key differences between the content of descriptions generated from architecture work and that generated from design work is in their use of principles.” [4]	"Whereas design and engineering work is primarily deductive in nature, architecture work is primarily inductive." [4]
Separation of end goals	**Difference in guiding principles,** architecture work and design work are performed in different ways	**Difference in reasoning approach**

[4] Rivera R. Am I Doing Architecture or Design Work? *IT Prof Mag*. 2007;9(6):46-48. doi:10.1109/MITP.2007.107

Discussion

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Apparent Assumption of Shared Knowledge

- Of the 87 sources examined:
  - 27 had a definition of either architecting or designing
  - 18 had no definitions at all
- Source authors may be assuming that the meaning of architecting and designing are understood by the community
- A totally consistent understanding between all stakeholders is unlikely

Coding may Reflect Practitioner Position and Structure/Flow Biases

- *Information* and *Subset* constitute about 75% of all coding. This may reflect:
  - Engineers, managers, and designers that deal with architecting may be higher in the organizational structure; and may be disproportionately represented in the sources; *Information* and *Subset* are more organizational and managerial
  - A SE bias that considers form and structure (such as flow and hierarchy) but not “implementation details”
- *Responsibilities* occurs much more rarely (~10%)
  - Perhaps reflecting its “implementation specific” nature

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Not Fully Considering Responsibilities May Have Negative Consequences In Practice

- *Responsibilities* occurs relatively rarely (~10%)
- Uncertainty on individual or team responsibilities may lead to
  - Ambiguity
  - Excessive back-and-forth
  - Dropped work
  - Etc.

Sequential Timing May Make Projects More Vulnerable To Engineering Change

- *Timing* is the 3rd most common comparison (18)
- Within *timing*, architecting preceding designing is the most common subcode comparison (10)
- There may be a preference for linear lifecycle models
- Several collected sources [5, 6] describe change as almost inevitable in engineering projects
- Linear lifecycle models may struggle in practice as a result

[5] Jarratt T, Eckert C, Caldwell N, Clarkson P. Engineering change: an overview and perspective on the literature. *Res Eng Des.* 2011;22(2):103-124. doi:10.1007/s00163-010-0097-y
[6] Bounova G, Keller R, Eckert C, Clarkson PJ. Change Propagation Analysis in Complex Technical Systems. *J Mech Des.* Published online 2009.

Further Nuance May Be Required For The Different Types Of Designing And Architecting

- Architecting sometimes occurred within designing and vice versa depending in part on whether designing was system level or detailed
- Sources mentioned several types of architectures, including:
  - Logical
  - Functional
  - System
  - Physical
- Each type of architecture may have its own issues contrasting against designing

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Granularity Is Distinguished From Other Codes

- For instance, in the quote:
  - "System Architecture is more abstract, conceptualization oriented, global, focused to achieve the mission and operational concept, and focused on high level structure in (sub) systems." [7]
  - "System Design is more technology oriented through physical, structural, environmental, operational properties forcing decisions for implementation." [7]
- Quotes don't compare tasks *(Subset)*
- Quotes don't compare information flow *(Information)*
- Quotes don't compare sequence of events *(Timing)*

[7] Faisandier, A., *Systems Architecture and Design*. Vol 3. Sinergy'Com; 2012.

Sub Task 1 Conclusions

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Limitations

- Interpretation of author language/coder bias
  - We must interpret the language of the source with our experience and understanding of the terminology.
- Source author bias
  - Authors have motivations and context to their works.
- Publication bias
  - Certain types of sources, sponsors, or sources with positive findings are more likely to be published.
- Non-english sources
  - Only sources written in English were included.

Conclusions - Differences

- RQ: What are the stated, perceived differences and similarities between systems designing and systems architecting in the academic literature?
- Differences:
  - Architecting informs designing
  - Architecting happens prior to designing
  - Architecting has a wider breadth of concern than designing
  - Architecting and designing are performed by different teams/individuals

Conclusions - Differences

- The top differences between architecting and designing in each major code are
  - Timing: sequential, architecting first (10)
  - Information: architecture inform design (26)
  - Subset: architecting within design (11)
  - Responsibilities: different teams/individuals (6)
  - Granularity: architecture overarching/design detailed (16)

- These top differences account for approximately 57% of all comparisons. Two subset comparisons are notable for occurring more frequently than the top responsibilities comparison.
  - Subset: design within architecting (7)
  - Subset: partial overlap (9)

Conclusions - Similarities

- RQ: What are the stated, perceived differences and similarities between systems designing and systems architecting in the academic literature?
- Similarities; Some sources state the two processes:
  - Are the same thing or occurring within the same parent process
  - Happen at the same time
  - Similar breadth of concern
  - Are performed by the same team/individual

Conclusions - Similarities

- Within the comparisons, six subcodes indicated similarities in the way sources described architecting and design.
  - Timing: simultaneous (3)
  - Information: both inform each other (6)
  - Subset: identical (4)
  - Subset: both subsets of SE or larger process (3)
  - Responsibilities: same team/individual (3)
  - Granularity: both similar breadth of focus (1)
- Together, this accounted for approximately 16.5% of all comparisons, suggesting that architecting and designing are more frequently described as different processes.

Conclusions – No Consensus

- Subset, timing, and responsibilities appear to lack a strong consensus among the subcode comparisons
- For instance, subset contains:
  - 18 comparisons saying architecting and designing are different
  - 7 comparisons saying they are similar
  - 9 comparisons (partial overlap) saying they have some amount of similarity and difference
- Raises not just the question of how the literature thinks of architecting and designing as different, but if they are different

Future Work

- Single definition codes
  - Current work examined explicit comparisons
  - Having codes for single definitions may allow more robust analysis
- Code correlations
  - Which comparisons are most often seen together
- Intra-source contradictions
  - Are sources consistent?
  - Do sources contradict themselves in ways that show conceptual ambiguity?
- Roles comparison
  - If Responsibilities is important but under examined, what are the roles of architects, designers, and systems engineers in the literature?

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Thank you!

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