Theory-Grounded Guidelines for Solver-Aware System Architecting (SASA)

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This material is based upon work supported by the National Science Foundation under CMMI EDSE Grants 2129574 and 2129539
Background - Open Innovation Crowdsourcing Mechanism

- STEM Agencies are increasingly using Open Innovation (OI), more specifically the Crowdsourcing Mechanism.

Seeker Organization ➔ Problem ➔ Broadcasting Problem + Incentives ➔ Set of Solution(s) ➔ Individual Solvers in the Crowd respond based on streamed benefits/costs.
Increased use of prizes, path to novelty?

‘Prizes are great, but they can’t actually solve my [complex] core problems…’
  — typical engineer

‘You get a lot of unicorns… is it novel if they’ll never work?’
  — experienced exec

Barrier: need better understanding of link among prize design, novelty and quality, before introducing strategies to drive novelty.

Source: Gallo, M. 2018
Theory: How prizes generate “better”

- General agreement that broadcasting yields quality, but nature and role of novelty in that process varies across theories.

**Random** draws: dist. over solution quality; *novelty* incidental.


**Talent** search: dist. over different solvers; some yield high quality.


**New perspective**: dist. over solving approaches; novel approaches yield quality.

Jeppesen and Lakhani 2010, Poetz and Schrier 2012, Franzoni and Sauermann 2014
Focus of my work

• Relationship between problem framing (decomposition) and solution novelty:
  1. How to characterize novelty distribution of solutions.
  2. What is the relationship between the scope of the problem and the resultant novelty distribution?

• Knowing this is important beyond prize competitions:
  ➢ Affects how we build design teams and present challenges to them.

• Approach: leverage data from the OI experiment
  ➢ data on problem -> solver -> solution chain
Experiment Overview
Robotic Arm Field Experiment

• Designed to look directly at distribution of the "crowd" and their solutions with respect to interest, follow-through and capability, on a problem that would address engineering skepticism.
Data Summary

Registration Survey

16000+ registered Freelancers

Demographics, work and educational history, motivation, self-reported distance/expertise etc.

Submission

263 solutions

Exit Survey

143 solvers across 17 contests

Motivation, contest-specific effort and learning, past similar projects etc.

Interest Tracking Data

3900 interested Freelancers

Detailed design documentation, incl. drawings, flow charts, analysis
Solution Characterization
Functional coding of each solutions

• All challenges relate to the design of an autonomous robotic manipulator. Global functions include: reach, grasp, pack, orient, control etc.

• For each function, coded how a solution achieved that function, based on Shah et al. tree structure.
Functional coding of each solutions

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Challenge</th>
<th>Description</th>
<th>Electronics</th>
<th>Planning</th>
<th>ControlFree</th>
<th>Space</th>
<th>Control Onto</th>
<th>Handrail</th>
<th>Control Orient</th>
<th>Control Ob1</th>
<th>Contingency/ Loading</th>
<th>Packing/Unpack</th>
<th>Reaching</th>
<th>Grasping</th>
<th>Orient</th>
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<td>SRA</td>
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</table>
Measures of Novelty

• Genealogical Categorization (Shah et al 2003)
• Ideas separated by physical principles used to satisfy each function

• NASA roboticists -> conventional solution (ground truth)
• How separated from the conventional solution is the user submission for each challenge
• Distance measured using generational distance
• function -> physical principles -> working principles sharing same physical principles -> embodiment -> detail
Generational Distance

Grasping

N = 2

N = 1

N = 1

N = 2
Aggregating at functional level

• Currently comparisons are made at a functional level across challenges

• We use an average novelty score to combine the individual scores

• Novelty score = \frac{3\times(#) + 2\times(#) + 1\times(#) + 0\times(#)}{Total\ Solutions}

• This is an average over the set which helps to aggregate and give a single value for each function

• Going ahead we need ways to aggregate for challenges with different functions – not addressed in literature

• Methods available rely on a subjective aggregation using arbitrary weights assigned by experts
Results
Distribution of Novelty scores

Grasp Across Challenges

Challenge

Increasing functional scope
Solutions to Grasp across challenges

• Visualize with Sankeys – shows how different solvers attempted it in comparison to the NASA solution
Solutions to Grasp across challenges

- Same function, different decompositions and framing
Explaining impact of decomposition

Less Novelty/Variety

- Low complexity; limited possibility
- Very complex: people stick to traditional methods, attract experts

More Novelty/Variety

- More complex: more possibilities
- Less complex: less distractions, can focus more on individual parts

Hypothesis: Bathtub curve in the novelty vs functional scope plot
Novelty Score vs Functional Scope

The graph shows the relationship between novelty score and functional scope. Different challenges are represented by different colored dots: grasp (red), pack (green), and reach (blue). The x-axis represents the functional scope ranging from 2 to 10, while the y-axis represents the novelty score ranging from 0 to 3.
Summary of my work

• There seems to be a more nuanced relationship here
  ➢ More work needs to done to fully characterize
  ➢ Use of alternate methods for analysis
  ➢ Better understanding the factors at play here
  ➢ We need to understand relationship between novelty and quality

• Ongoing work, looking at aggregating beyond single function (not currently addressed in the literature)
Relationship to broader project

• Objective: Develop heuristics for how to architect systems to take advantage of the non-traditional contributions (e.g., from new contractors, or crowd actors)

Simple simulation proof-of-concept that “best” architecture depends on “who” solves

Extend modeling framework to address complex systems, like the manipulator presented here (this feeds characterization)

Developing RL-based tools to extract heuristics from the complex tradespaces that we will need to explore
The relationship to broader project

<table>
<thead>
<tr>
<th>Action Type</th>
<th>1. Choice of solver</th>
<th>2. Choice of decompositions</th>
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<tbody>
<tr>
<td>Action Number</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Action</td>
<td>Pro</td>
<td>Amateur</td>
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<tr>
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<td>Pro</td>
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The above table shows the complete action space
References


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THANK YOU

Stay connected with us online.

 skyrocketinggraphic.com
## 17 Astrobee Challenges

Manipulated functional scope and interdisciplinarity in fixed technology area

<table>
<thead>
<tr>
<th>Arch</th>
<th>Challenge</th>
<th>Prize</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>SRA – whole arm</td>
<td>$5000</td>
</tr>
<tr>
<td>2</td>
<td>SFA – Arm, no hand</td>
<td>$4000</td>
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<tr>
<td></td>
<td>SAM - hand</td>
<td>$1500</td>
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<tr>
<td>3</td>
<td>SCA - Shoulder</td>
<td>$1500</td>
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<td>SPAM – Elbow down</td>
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<td>4</td>
<td>EMA – Arm mechanisms</td>
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<td>CDPD – Arm electronics</td>
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<td>RASA – Arm software arch</td>
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<td>PSA – Pointing architecture</td>
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<th>Challenge</th>
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<td>EDC – elec clam</td>
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<td>SDM - joint</td>
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<td>MIS – finger surface</td>
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<tr>
<td>EBD – Electronics box</td>
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<td>BMA – Box analysis</td>
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