Statistical Matchmaking

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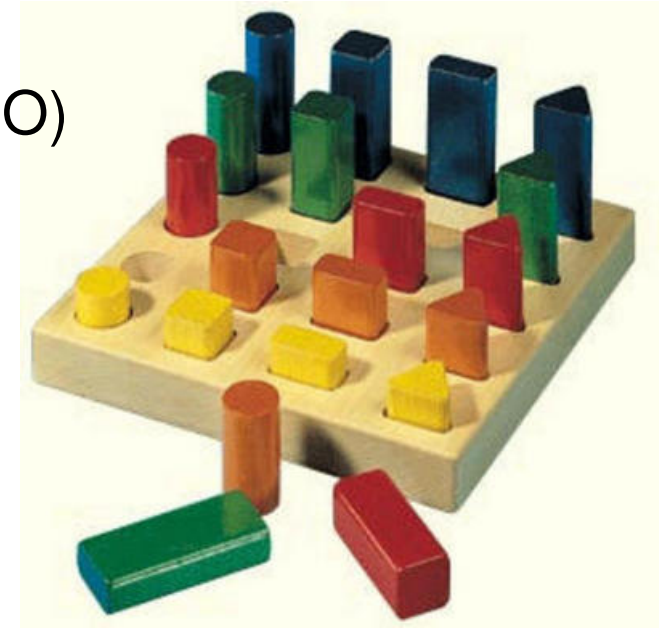
What Is Matchmaking?

The Standard Approach

Description, description, description

- ABSI,SHADE,COINS,LARKS (KQML)
- Semantic Web Services (OWL-S,WSMO)



All focus on the ‘type’ system

- Syntactic similarity (string matching)
- Description logic (subsumption)

The result of using the Semantic Web is an unambiguous description of the interface of the Web service which is machine understandable and provides the basis for a seamless interoperation among different services

What's Wrong with Semantic Descriptions?

- Limited expressiveness of capability description languages
- Developers unlikely to be knowledge representation experts
- Developers are lazy
- Arbitrary inter-relationships not known to the service provider
- Comprehensive constraints too expensive to generate or use
- Providers like some privacy (or lie)
- Mediation = mismatches
- DL reasoners disagree
- Sometimes descriptions are just broken: bugs happen

What Don't They Tell Us?

How agents *actually* act

- Some services are simply better than others

How agents actually *interact*.

- Social relationships
- Inter-business partnerships
- Software components designed different groups
- Resources or constraints shared between providers
- Some people don't want to coöperate

Static and stand-alone not dynamic and networked

Solution

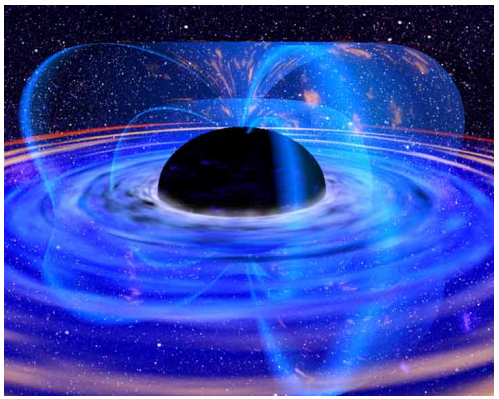
Performance Monitoring
[Zhang and Zhang, 2002], [Xiaocheng Luan et al., 2004]

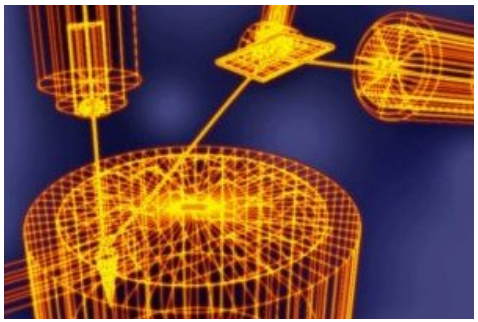
- Ask the service user about satisfaction
- Use that data to improve selection

Multiparty matchmaking

- LCC makes multi-party dialogues easy to specify
- Incidence calculus enables combination

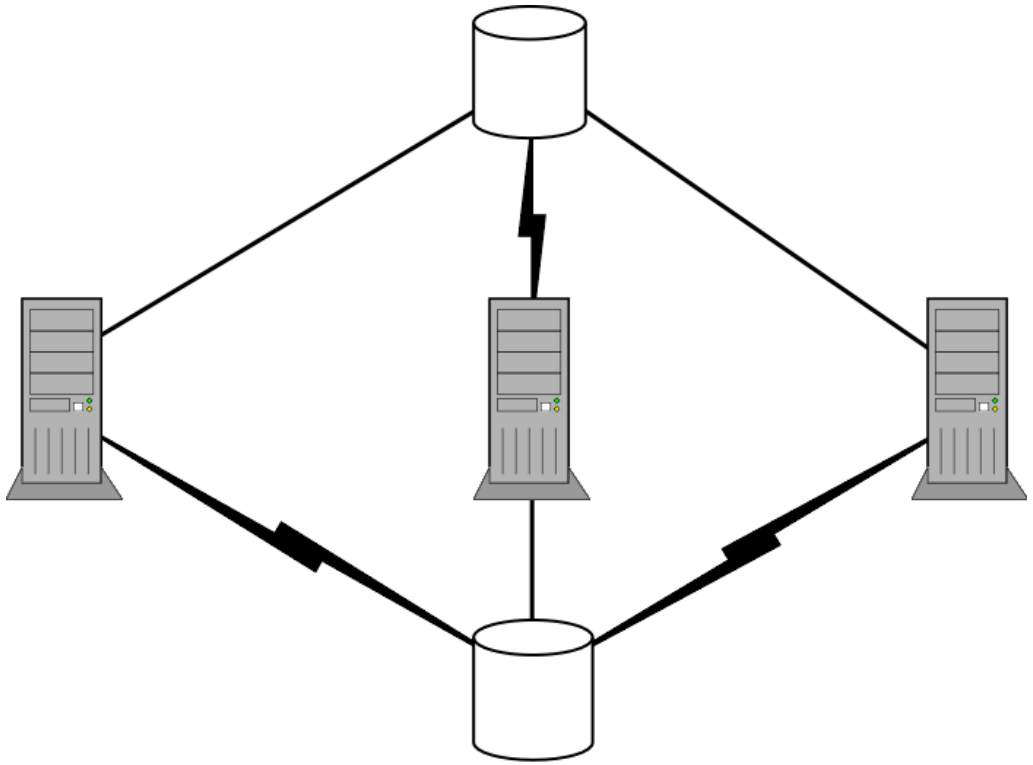
Astrid Looks for Black Holes



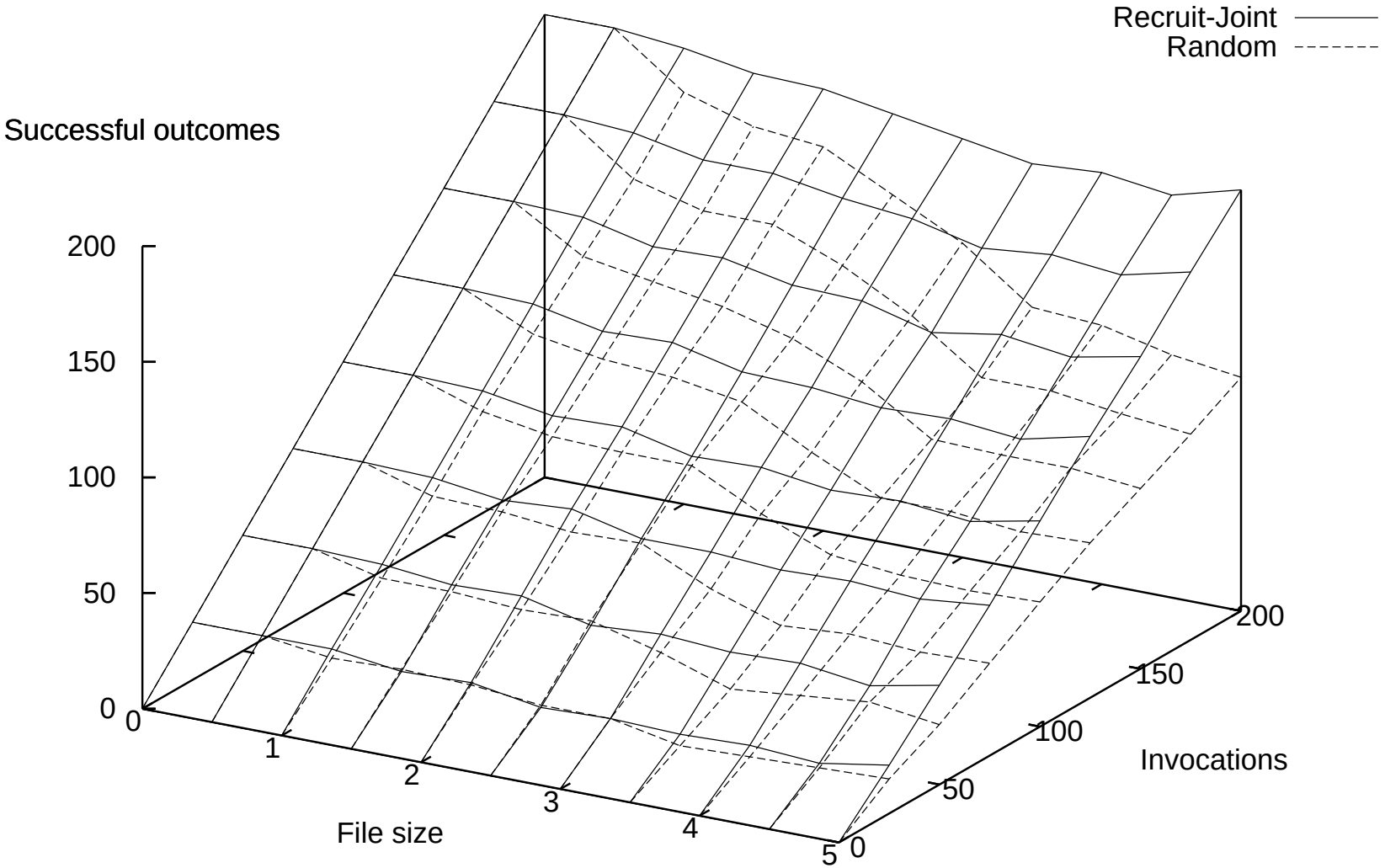


What Astrid and the Matchmaker Don't Know

The network bandwidths are different



Results


Recruit-Joint
Random
Successful outcomes
200
150
100
50
0
0
1
2
3
4
5
File size
0
50
100
150
200
Invocations

Lightweight Coördination Calculus

- Based on electronic institutions and process calculi
- Agents have names and adopt roles
- A protocol is a set of role definitions specifying the message space
- Based on electronic institutions and process calculi

$$
\begin{array}{l}
a(astronomer(File), Astronomer) :: \\
\quad search(File) \Rightarrow a(black\text{-}hole\text{-}finder, BHF)\ then \\
\quad \left(\begin{array}{l} success \Leftarrow a(black\text{-}hole\text{-}finder, BHF)\ then \\ receive\_visualisation(Thing, V) \leftarrow \\ \qquad visualising(Thing) \Leftarrow a(visualizer, V) \end{array} \right) \\
\quad or \\
\quad failed \Leftarrow a(black\text{-}hole\text{-}finder, BHF)
\end{array}
$$

Lightweight Coördination Calculus Rewrite Rules

$$A :: B \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, O} A :: E \quad \text{if} \quad B \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, O} E$$

$$A_1 \text{ or } A_2 \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, O} E \quad \text{if} \quad \neg \text{closed}(A_2) \wedge A_1 \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, O} E$$

$$A_1 \text{ or } A_2 \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, O} E \quad \text{if} \quad \neg \text{closed}(A_1) \wedge A_2 \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, O} E$$

$$A_1 \text{ then } A_2 \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, O} E \text{ then } A_2 \quad \text{if} \quad A_1 \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, O} E$$

$$A_1 \text{ then } A_2 \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, O} A_1 \text{ then } E \quad \text{if} \quad \text{closed}(A_1) \wedge \text{collaborators}(A_1) = \mathcal{C}' \wedge A_2 \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}', O} E$$

$$C \leftarrow M \Leftarrow A \xrightarrow{M_i, M_i \setminus \{M \Leftarrow A\}, \mathcal{P}, \mathcal{C}, \emptyset} c(M \Leftarrow A, \mathcal{C}) \quad \text{if} \quad (M \Leftarrow A) \in M_i \wedge \text{satisfy}(C)$$

$$M \Rightarrow A \leftarrow C \xrightarrow{M_i, M_i, \mathcal{P}, \mathcal{C}, \mathcal{C}', \{M \Rightarrow A\}} c(M \Rightarrow A, \mathcal{C}') \quad \text{if} \quad \text{satisfied}(C) \wedge \mathcal{C}' = \text{extendcollaborators}(\mathcal{P}, \mathcal{C}, \text{role}(A))$$

$$\text{null} \leftarrow C \xrightarrow{M_i, M_i, \mathcal{P}, \mathcal{C}, \emptyset} c(\text{null}, \mathcal{C}) \quad \text{if} \quad \text{satisfied}(C)$$

$$a(R, I) \leftarrow C \xrightarrow{M_i, M_o, \mathcal{P}, \mathcal{C}, \emptyset} a(R, I) :: B \quad \text{if} \quad \text{clause}(\mathcal{P}, C, a(R, I) :: B) \wedge \text{satisfied}(C)$$

$$\begin{aligned} \text{collaborators}(c(\text{Term}, \mathcal{C})) &= \mathcal{C} \\ \text{collaborators}(A_1 \text{ then } A_2) &= \text{collaborators}(A_1) \cup \text{collaborators}(A_2) \\ \text{collaborators}(A :: B) &= \text{collaborators}(A) \cup \text{collaborators}(B) \end{aligned}$$

Lightweight Coördination Calculus Example

$a(astronomer(File), Astronomer)$ ::

$$search(File) \Rightarrow a(black\text{-}hole\text{-}finder, BHF)\ then$$
$$\left(\begin{array}{l} success \Leftarrow a(black\text{-}hole\text{-}finder, BHF)\ then \\ receive\_visualisation(Thing, V) \\ \quad \leftarrow visualising(Thing) \Leftarrow a(visualizer, V) \end{array}\right)$$
$$or$$
$$failed \Leftarrow a(black\text{-}hole\text{-}finder, BHF)$$

$a(black\text{-}hole\text{-}finder, BHF)$ ::

$$search(File) \Leftarrow a(astronomer(File), Astronomer)\ then$$
$$grid\text{-}ftp\text{-}get(File) \Rightarrow a(astronomy\text{-}database, AD)\ then$$
$$\left(\begin{array}{l} grid\text{-}ftp\text{-}sent(File) \Leftarrow a(astronomy\text{-}database, AD)\ then \\ success \Rightarrow a(astronomer, Astronomer) \\ \quad \leftarrow black\_\ hole\_\ present(File, Black\_\ hole)\ then \\ visualise(Black\_hole, Astronomer) \Rightarrow a(visualizer, V) \end{array}\right)$$
$$or$$
$$failed \Rightarrow a(astronomer(File), Astronomer)$$

$a(astronomy\text{-}database, AD)$ ::

$$grid\text{-}ftp\text{-}get(File) \Leftarrow a(black\text{-}hole\text{-}finder, BHF)$$
$$grid\text{-}ftp\text{-}sent(File) \Rightarrow a(black\text{-}hole\text{-}finder, BHF)$$
$$\leftarrow grid\_\ ftp\_\ completed(File, AD)$$

$a(visualizer, V)$ ::

$$visualise(Thing, Client) \Leftarrow a(?, Requester)\ then$$
$$visualising(Thing) \Rightarrow a(?, Client) \leftarrow serve\_visualisation(Thing, Client)$$

Incidence Calculus

- Probability calculus based on sets of possible worlds
- Propositions true of certain subsets of worlds
- Logical operations based on set operators $\wedge = \cap$, $\vee = \cup$
- Need exact information about what happened
- But get more accurate results for compound formulae
- Compound formulae = agent interactions

$$
\begin{aligned}
i(\top) &= \mathit{worlds} \\
i(\bot) &= \{\} \\
i(\neg\alpha) &= i(\top) \backslash i(\alpha) \\
i(\alpha \wedge \beta) &= i(\alpha) \cap i(\beta) \\
i(\alpha \vee \beta) &= i(\alpha) \cup i(\beta) \\
i(\alpha \rightarrow \beta) &= i(\neg\alpha \vee \beta) = \mathit{worlds} \backslash i(\alpha) \cup i(\beta)
\end{aligned}
$$

$$
p(\alpha) = \frac{|i(\alpha)|}{|i(\top)|} \qquad p(\alpha|\beta) = \frac{|i(\alpha \wedge \beta)|}{|i(\beta)|}
$$

In general, $p(a \wedge b) \neq p(a)p(b)$

Incidence Calculus Example

$$
\begin{aligned}
\mathit{worlds} &= \{\mathit{alice}, \mathit{bob}, \mathit{claire}, \mathit{dan}, \mathit{edith}, \mathit{frank}\} \\
i(\mathit{likes\text{-}coffee}) &= \{\mathit{alice}, \mathit{bob}, \mathit{claire}\} &= \frac{1}{2} \\
i(\mathit{likes\text{-}tea}) &= \{\mathit{dan}, \mathit{edith}, \mathit{frank}\} &= \frac{1}{2} \\
i(\mathit{likes\text{-}cookies}) &= \{\mathit{alice}, \mathit{bob}, \mathit{claire}, \mathit{dan}\} &= \frac{2}{3}
\end{aligned}
$$

$$
\begin{aligned}
i(\mathit{likes\text{-}coffee}) \wedge i(\mathit{likes\text{-}coookies}) &= \{\mathit{alice}, \mathit{bob}, \mathit{claire}\} &= \frac{1}{2} \\
i(\mathit{likes\text{-}tea}) \wedge i(\mathit{likes\text{-}cookies}) &= \{\mathit{dan}\} &= \frac{1}{6}
\end{aligned}
$$

$$
\begin{aligned}
P(\mathit{likes\text{-}coffee} \mid \mathit{likes\text{-}coookies}) &= \frac{|\{\mathit{alice},\mathit{bob},\mathit{claire}\}|}{|\{\mathit{alice},\mathit{bob},\mathit{claire},\mathit{dan}\}|} &= \frac{3}{4} \\
P(\mathit{likes\text{-}tea} \mid \mathit{like\text{-}cookies}) &= \frac{|\{\mathit{dan}\}|}{|\{\mathit{alice},\mathit{bob},\mathit{claire},\mathit{dan}\}|} &= \frac{1}{4}
\end{aligned}
$$

Execution Histories

$$i(outcome(good), [1,2,3,4,6,10,11,12,16,22,23,24])$$
$$i(col(astronomy\text{-}database, greenwich), [18,19,20,21,22,23,24,25])$$
$$i(col(astronomy\text{-}database, herschel), [10,11,12,13,14,15,16,17])$$
$$i(col(astronomy\text{-}database, keck), [1,2,3,4,5,6,7,8,9])$$
$$i(col(black\text{-}hole\text{-}finder, barcelona\text{-}sc), [8,9,16,17,24])$$
$$i(col(black\text{-}hole\text{-}finder, ucsd\text{-}sdsc), [1,2,3,4,10,11,12,13,18,19,20])$$
$$i(col(black\text{-}hole\text{-}finder, uk\text{-}hpcx), [5,6,7,14,15,21,22,23])$$

$$= i\left(outcome(good) \middle| \begin{array}{l} col(black\text{-}hole\text{-}finder, ucsd\text{-}sdsc) \wedge \\ col(astronomy\text{-}database, herschel) \end{array} \right)$$
$$= \frac{|\{10,11,12\}|}{|\{10,11,12,13\}|} = \frac{3}{4}$$

RECRUIT-JOINT

```
RECRUIT-JOINT(database, protocol)
1  roles ← ROLES-REQUIRED(protocol)
2  collaborations ← ALL-COLLABORATIONS(database, protocol, roles)
3  for c ∈ collaborations
4       do quality[c] ← PROBABILITY-GOOD-OUTCOME
                        (database, protocol, c)
5  return ARGMAX(collaborations, quality)
```

$$argmax_{AD,BHS,V} \; P\left(\begin{array}{l} col(astronomy\text{-}database, AD) \wedge \\ col(black\text{-}hole\text{-}finder, BHS) \wedge \\ col(visualizer, V) \wedge outcome(good) \\ \mid protocol(\text{BLACK-HOLE-SEARCH}) \end{array}\right)$$

RECRUIT-INCREMENTAL

RECRUIT-INCREMENTAL(*protocol*, *database*, *role*)

```
1  for r ∈ ACTIVE-ROLES(protocol)
2       do collaborators[r] ← COLLABORATOR-FOR-ROLE(protocol, r)
3  candidates ← CAPABLE-AGENTS(database, role)
4  for c ∈ candidates
5       do collaborators[role] ← c
6          quality[a] ← PROBABILITY-GOOD-OUTCOME
                        (database, protocol, collaborators)
7  return ARGMAX(candidates, quality)
```

$$argmax_{AD} \quad P\left(\begin{array}{l} col(astronomy\text{-}database, AD) \ \wedge \ outcome(good) \\ \Big| \ protocol(\text{BLACK-HOLE-SEARCH}) \wedge \\ \Big| \ col(black\text{-}hole\text{-}finder, BHF) \end{array}\right)$$

Comparison

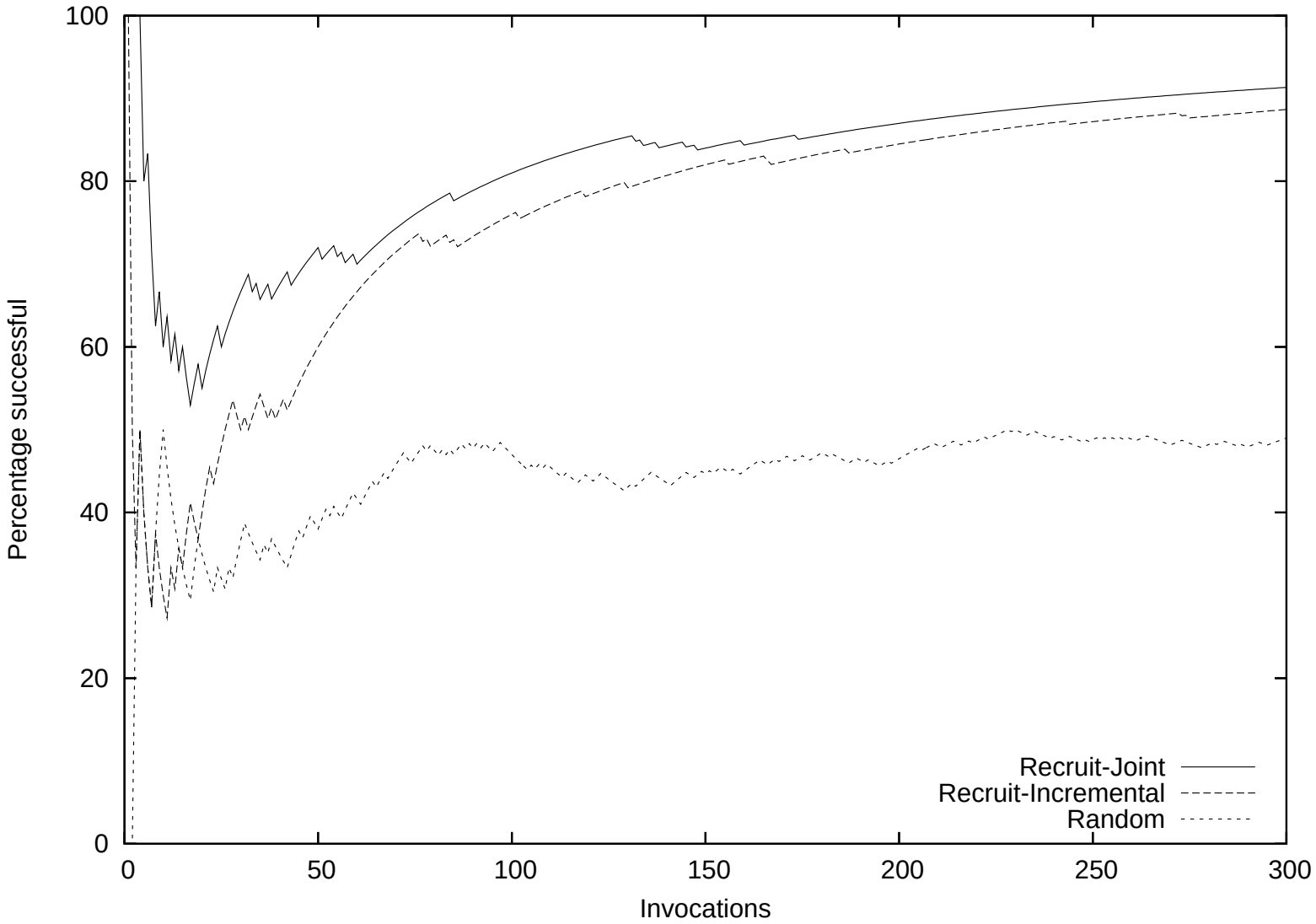
RECRUIT-JOINT

- ‘Optimal’ solution
- Computationally expensive
- Many protocols might never invoke all roles

RECRUIT-INCREMENTAL

- Computationally cheap
- Only considers those services actually invoked
- Possibly sub-optimal results

Results


100
80
60
40
20
0
Percentage successful
0
50
100
150
200
250
300
Invocations
Recruit-Joint
Recruit-Incremental
Random

Complexity

$$\prod_{r_i \in Roles} |providers(r_i)|$$

- i.e. exponentially bad in number of roles
- depends on the nature of
  - the provider population
  - protocol design

Conclusion

- Semantic matchmaking is not the whole answer
- Multi-party interactions need matchmakers, too
- Taking account of previous performance can improve outcomes
- A very simple strategy works

Future work

- Applying it to web services
- Other techniques for improving results (machine learning)
- Scaling up

Questions:

- Real-world web services with low cost and rich interactions
- Who'll pay for this computation?

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