Relevance Estimation for Evidence Marshalling

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Outline

- Goal:
  - Support evidence marshalling (EM) with automated reasoning
- Problem:
  - Infinite search spaces
  - Difficult to know if/when progress is being made
    - One step from "Eureka!"
- Proposed Solution: Relevance Estimation
  - Algorithms that guide EM searches and get better with experience
- Methods:
  - Test bed for evaluating relevance estimation and evidence marshalling

- Warning:
  - Not a lot of Soar in this story; mostly laying groundwork…

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Evidence Marshalling

- Process of “connecting the dots” to form a coherent narrative about a collection of evidences
  - Pop-culture Examples:
    - Sherlock Holmes
    - Procedural TV shows (Perry Mason, Law & Order)
  - Specialized human techniques for EM
    - Wigmorean analysis
- Many potential applications for automated methods:
  - Police investigations
  - Insurance fraud
  - Intelligence analysis

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Automating EM

- Automated reasoning techniques have been demonstrated as effective tools for EM in very restricted problem domains
  - cause-of-death conclusions from evidence
  - insurance fraud detection
- Limits to automated EM in open-ended domains
  - Hypothesis generation
  - Knowledge sources
  - Efficient control of search process

Automating EM: Near-term solutions

- Hypothesis generation:
  - In the near- to mid-term, no automated approach is likely to challenge human creativity
  - Our approach leverages user insight and experience by capturing their notions and "hunches" and then searching for confirming or disconfirming evidence
- Sources of knowledge
  - Trifles
    - Many existing automated sources: data extraction tools
  - Domain knowledge
    - Facts and inferences from applicable domain(s)
    - Increasing stores of general knowledge resources: Cyc, Semantic Web
- Efficient search
  - Must find intermediate hypotheses/assertions that can connect trifles to user hypotheses

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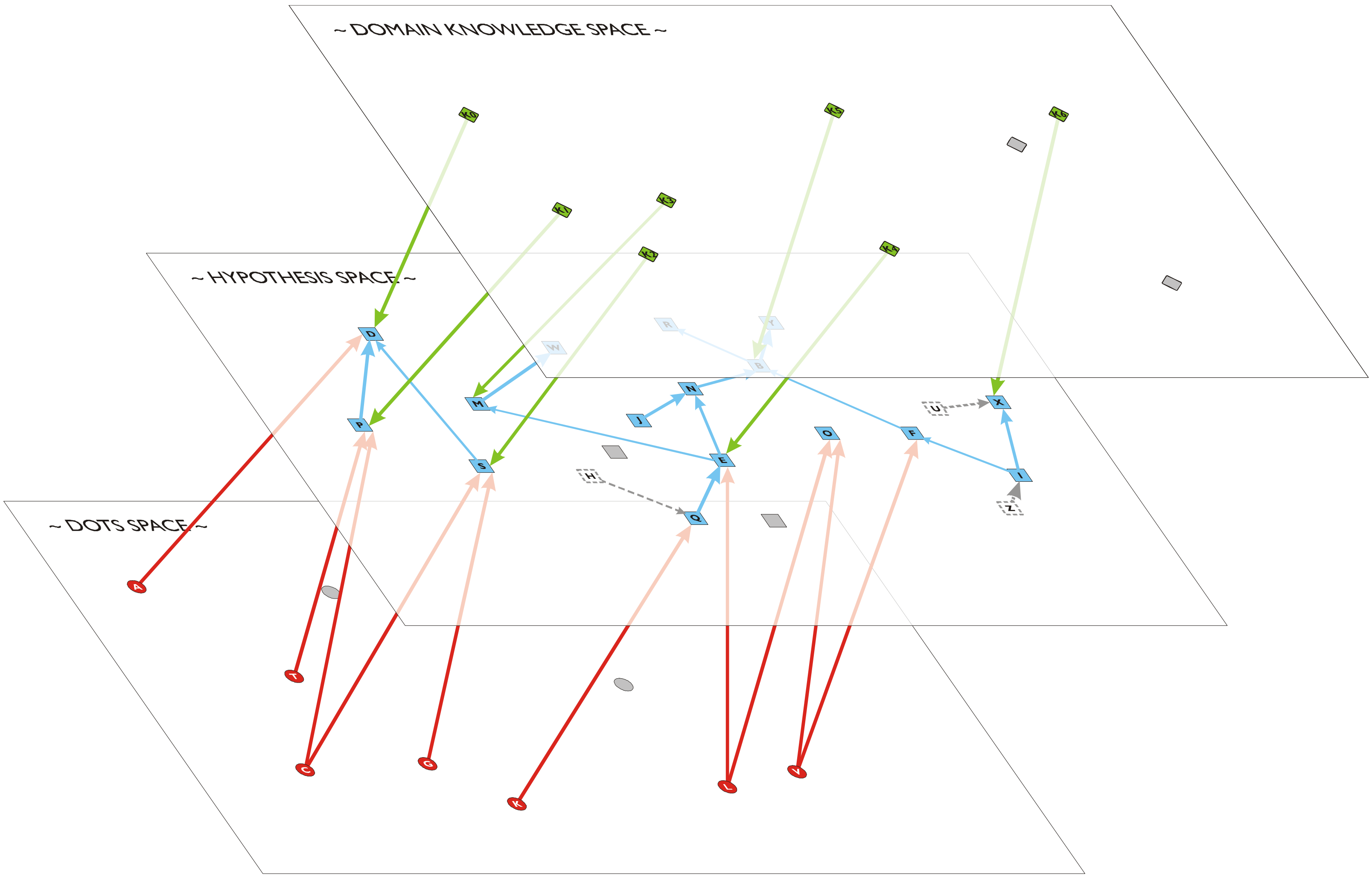
Challenge: Search Space is Infinitely Large

- Domain knowledge and trifles combine in infinitely many possible ways
  - Bill Clinton was POTUS in 1996
  - Hillary Clinton is Bill Clinton's spouse
  - …
- Difficult to judge if any individual intermediate hypothesis is getting closer to the goal
  - Hillary Clinton lived in the White House in 1996
- Multiple, simultaneous searches
  - Trifles: Which "trifles" are relevant
  - Domain knowledge: Which facts about the world are relevant?
  - Hypotheses: Which intermediate hypotheses are on the right track?
  - Confidence: Which assertions are more likely/probable?

Simultaneous searches



Hypothesis:
Efficient search for EM is a <u>solvable</u> challenge

- Evidence:
  - Although the search space is infinitely large, people perform evidence marshalling adequately
  - How?
    - Training & experience, tools (Wigmorean analysis)
    - “Natural” pruning of the search space
      - Humans generate heuristic choices (“hunches”) that can guide them thru very large search spaces
- Goal: explore computational methods for:
  - Generating and assessing “hunches” (relevance estimation)
  - Learning from experience to improve the relevance estimation process

Proposal: Relevance Estimation

- Goal: Evaluate the relevance/importance of each new assertion
  - Cannot assume system already "knows" the answer or knows that some new inference is an important "dot"
    - Many potential assertions can be generated
    - May not be obvious which assertions will actually be valuable or "relevant" to the problem (Avoid "wishful thinking")
  - Relevance estimation is the "strategy" for prioritizing direction(s) of reasoning and establishing "sufficiency" of a potential direction of reasoning
  - Context is important: Not evaluating in isolation
- Contributing methods:
  - Domain neutral: analogy, deduction, classification, etc.
  - Domain specific: social network analysis, model of user's interest
- Metrics for relevance determination:
  - complexity-based (Occam's razor)
  - graph-based (path length)
  - knowledge-based
    - information scent
    - ontological relationships

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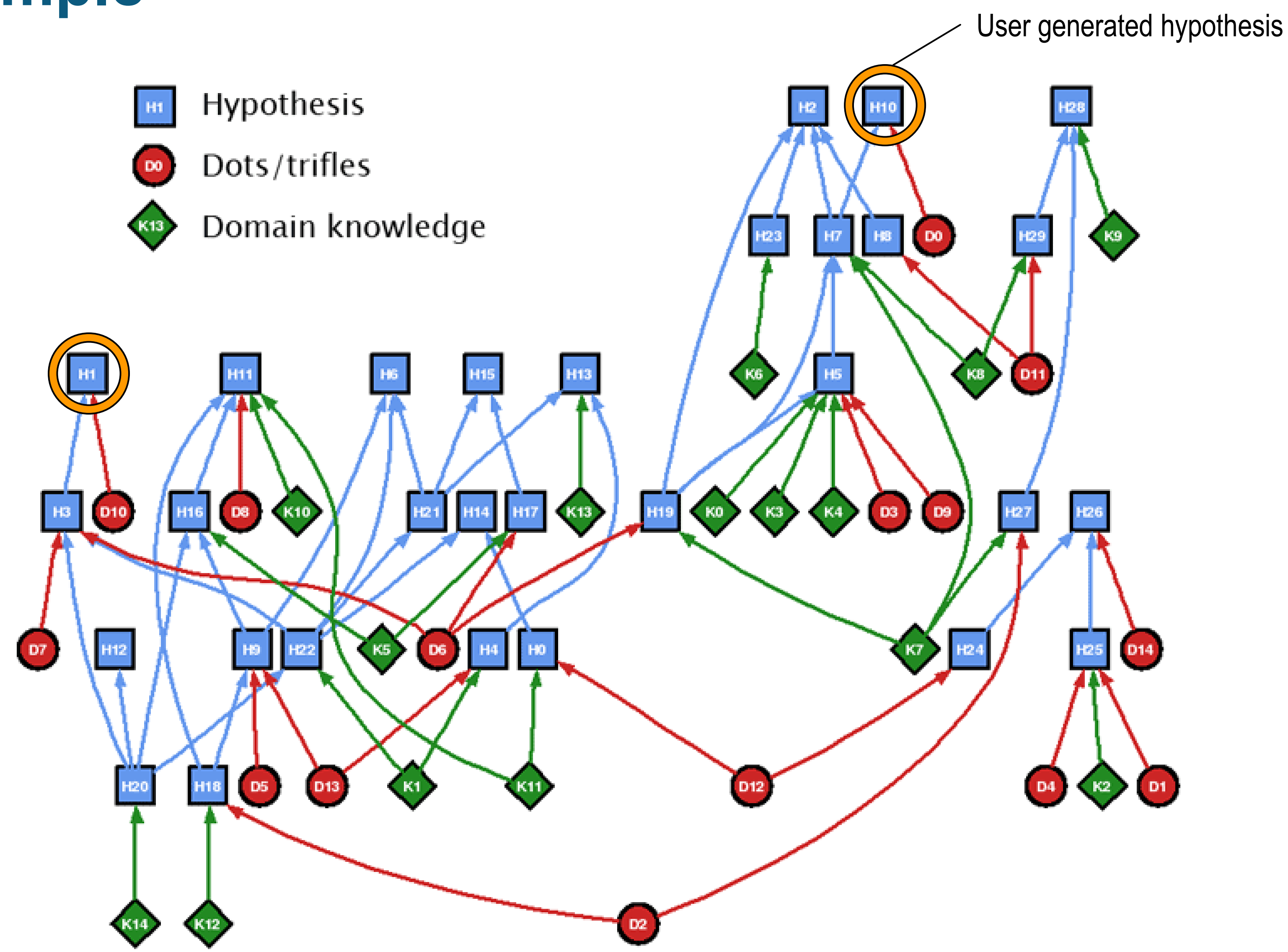
Test bed for RE/EM Research

- Problem:
  - Need large bodies of encoded knowledge to evaluate approaches to RE/EM
  - Access to “real” data is difficult for research purposes
    - security, sensitivity, size, etc.
- Proposed Approach:
  - Test bed for RE/EM
    - Automatically generate potential search spaces
    - Capture size and complexity of the space
    - Systematically vary parameters that represent the “connectedness” of possible hypotheses in the example
    - Simulate relevance across a number of orthogonal and over-lapping dimensions

Example


User generated hypothesis
Hypothesis
Dots/trifles
Domain knowledge

Simulating relevance in the test bed

- Relevance:
  - Predicts the likelihood of a relationship between m and n
  - Estimated by aggregating multiple knowledge sources
  - RE $= f(re_0, re_1, re_2, \ldots re_n)$, where re_i is a source of knowledge about the relationship between m and n
- Contributing knowledge sources, re_i, can include:
  - ontological relationships between m and n
  - semantic and syntactic similarity between m and n
  - completeness of analogical mapping between m and n
  - "cognitive" distance between m and n
  - expectation of success of getting to m and n
  - recognition of m in the context of n

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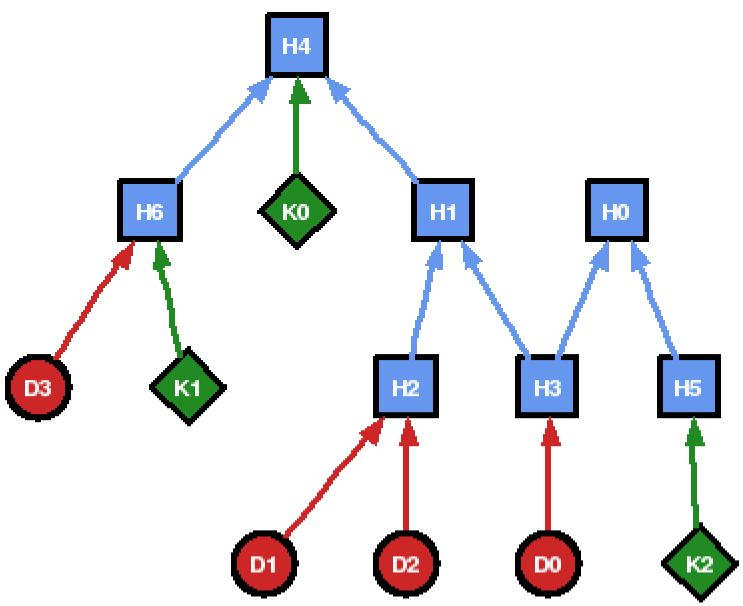
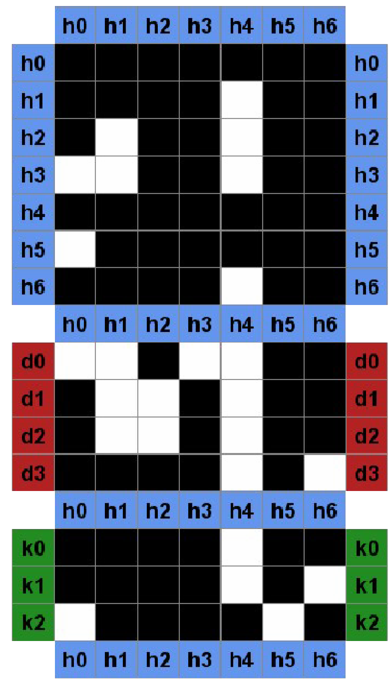
Simulating relevance in the test bed, cont'd

- Some sources can be simulated using graph theoretic operations, e.g., transitive closure in graph implies perfect knowledge of relations between dots, domain facts, and hypotheses.

pEM graph



TC matrix



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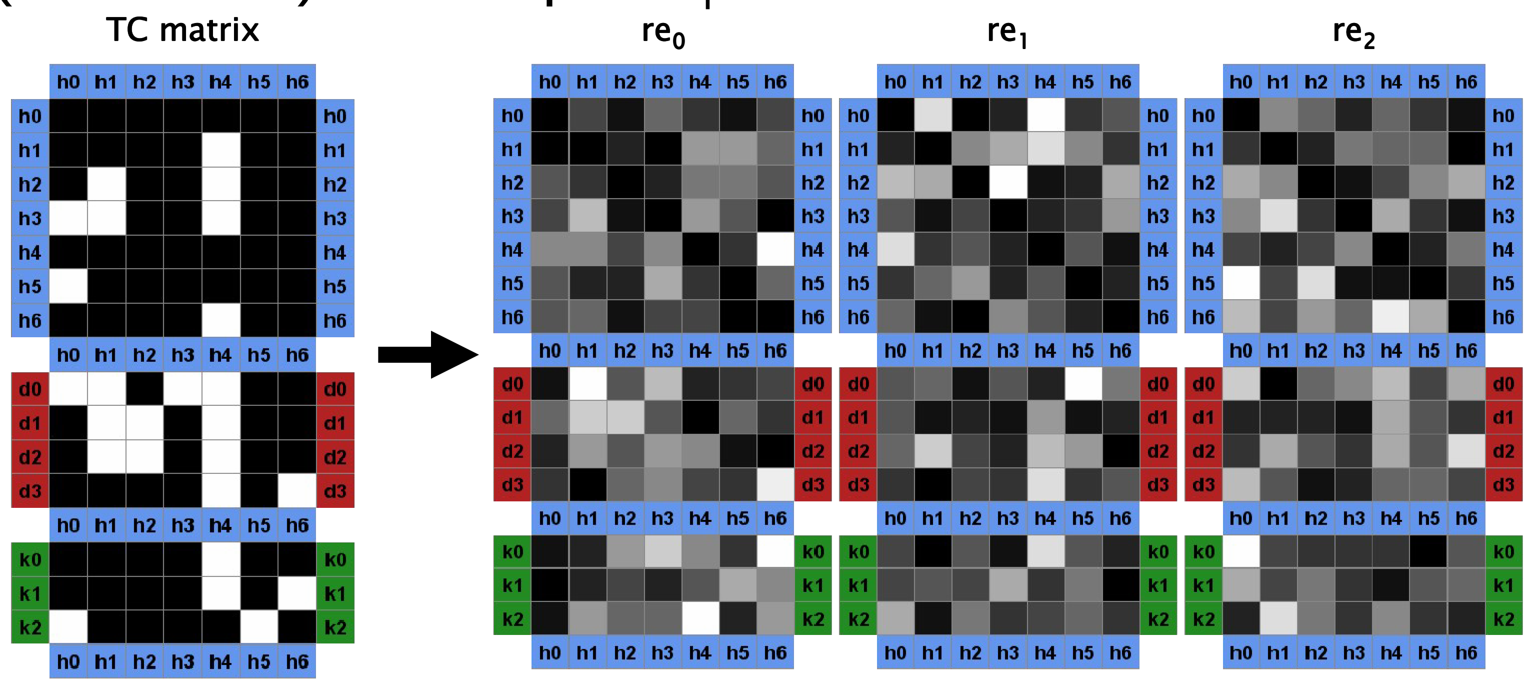
Simulating relevance in the test bed, cont'd

- Real knowledge is imperfect and from multiple, potentially contradicting, sources
- In the testbed, the perfect TC relationships are distributed (with noise) to multiple re_i matrices



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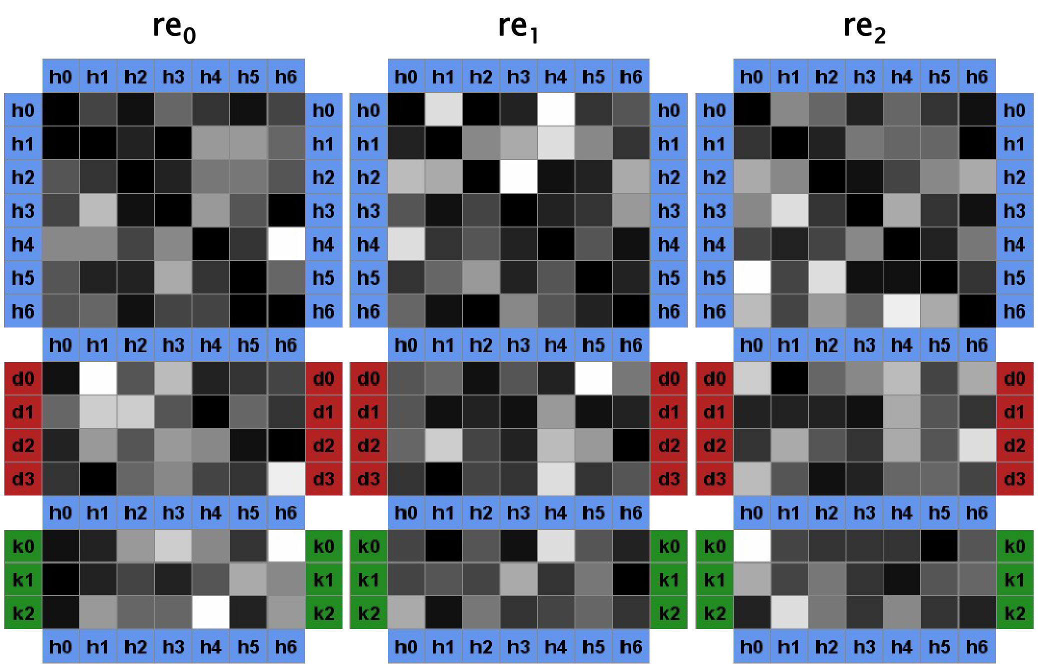
Simulating relevance in the test bed, cont'd

- Test bed facilitates:
  - Easy use of knowledge sources represented as a matrices
  - Explorations of how to aggregate noisy and contradictory knowledge



Aggregation options:

$\mathrm{RE}(m,n) = \Sigma c_j * re_i(m,n)$

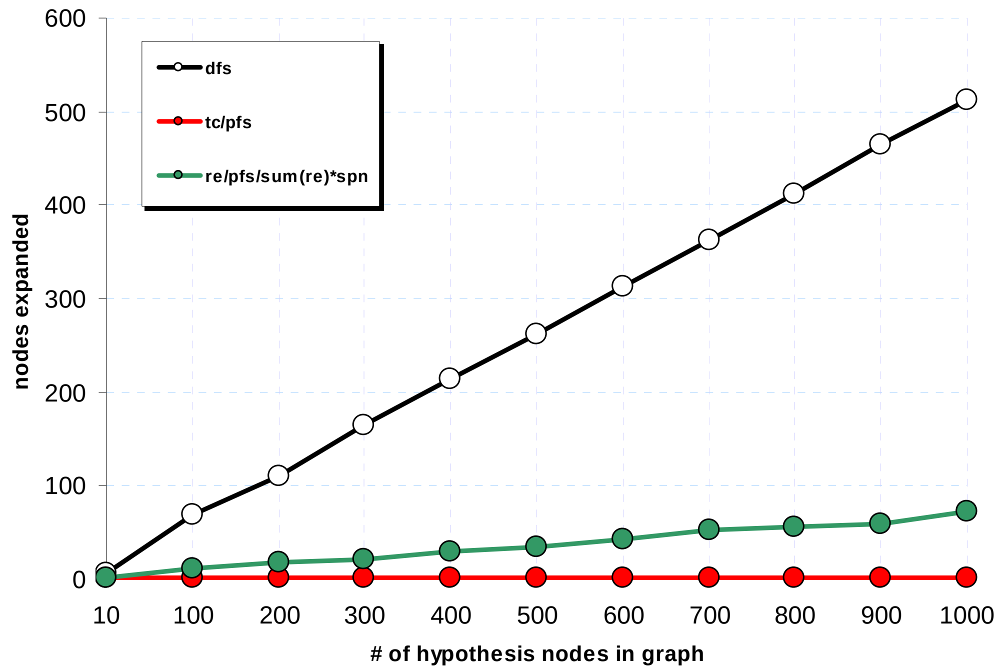
$\mathrm{RE}(m,n) = \max(re_i(m,n))$

$\mathrm{RE}(m,n) = \mathrm{avg}(re_i(m,n))$

$\mathrm{RE}(m,n) = \ldots$

Initial Results (1)

- Search for all nodes in pEM graphs
  - DFS: exhaustive knowledge-free search; upper-bound
  - TC: perfect knowledge give direct path to goal; lower bound
  - RE: RE(m,n) guides priority-first search;
    - 90% fewer expanded nodes in comparison to DFS



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Conclusions

- Humans provide evidence tractable search for EM is feasible and clues for how to do it
- Test beds can be developed for exploring search challenge without large, a priori investments in knowledge encoding
  - Proof-of-concept test bed can generate problems automatically for exploring the consequences of RE design options
  - Plan: Complement with open-source, real-world datasets
- Nuggets:
  - Interesting ideas about how to attack this problem
  - Developed simple testbed for exploring computational approaches
  - Rich literature from which to draw inspiration
- Coal:
  - No feasibility implementation/exploration of solution (“idea ware”)