Exploring Topological Environments

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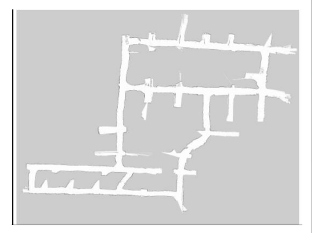
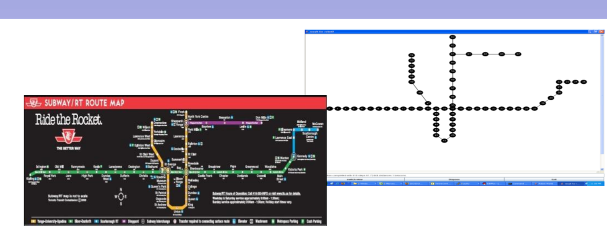
The problem

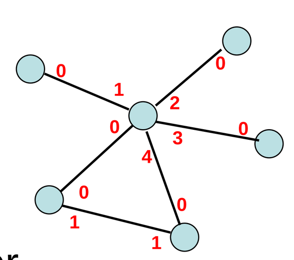
- ❑ How do we use mobile robot(s) to acquire spatial models of unknown physical environments?
- ❑ Fundamental problem in robotics, where it is known as **SLAM** (simultaneous localization and mapping)
- ❑ Robot(s) operate in an unknown environment
- ❑ Goal: build a map representation of the environment
- ❑ One fundamental problem: ***'have I been here before?'***
  - Disambiguate current place against known locations
- ❑ Two basic approaches to solving this problem
  - Metric information in probabilistic approaches
  - Resorting to an 'oracle' in deterministic approaches
- ❑ Here we are looking at deterministic approaches and the power of specific oracles



Basic world and robot model



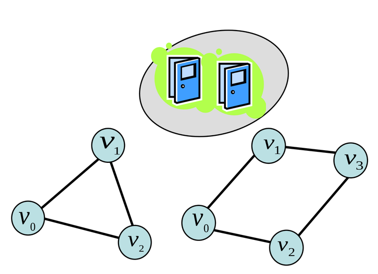
- ❑ The world is modelled as an embedding of an undirected graph with vertices and edges
- ❑ Explicit specification of edge ordering exists in each vertex
  - Inaccessible to robot – anonymous graph
- ❑ Robot can move within the environment by traversing edges
  - Identify when arriving at a vertex
- ❑ Robot can enumerate edges at a vertex in a consistent manner
  - Assign local labels to edges – permutations of the existing edge ordering



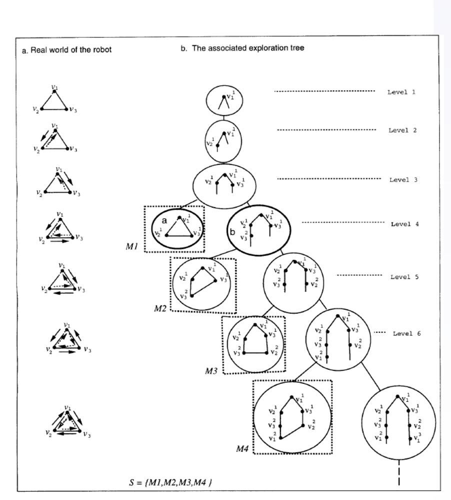
Is an 'oracle' necessary for exploration

YES!

- ❑ Robot cannot distinguish places using sensing
  - Observing (infinite) sequence of two-door rooms

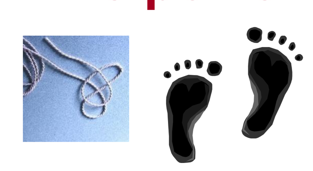


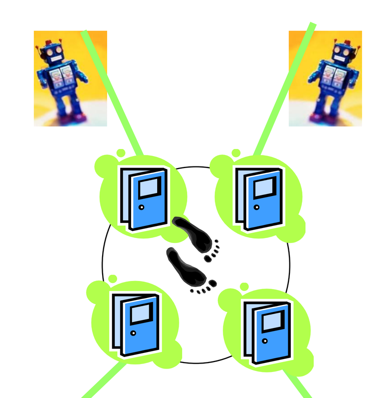
- ❑ At a 'new' place, consider <u>all</u> possibilities
  - Maintaining multiple hypotheses (true / false)
- ❑ No deterministic algorithm exists!
  - May be infinite valid models
  - But we can use an oracle to make the problem solvable deterministically



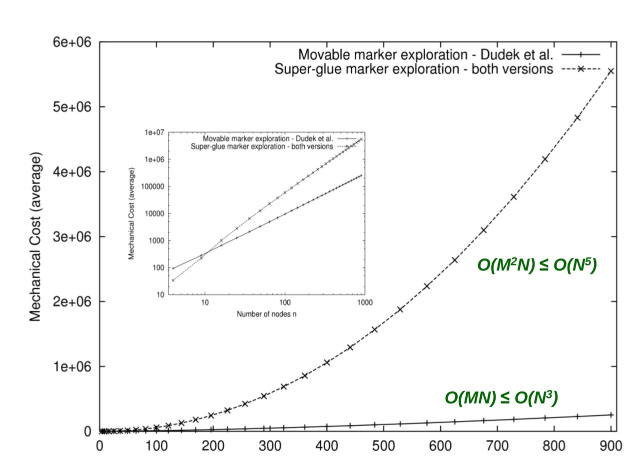
Various kinds of oracles

The power of a 'very weak' oracle





- ❑ **A super-glue pebble**
  - A footprint, a very short string, and the like
  - Marks exactly one place -- probably the weakest ?!
  - Is it sufficient?
  - ☒ **undirectional - no** ☑ **directional - yes.** ***$O(m^2n) \le O(n^5)$*** exploration cost.
  - Huge disambiguation cost!
- ❑ **A movable pebble**
  - Marks one place at a time.
  - An <u>undirectional</u> pebble is sufficient!
  - ☑ ***$O(mn) \le O(n^3)$*** exploration cost.



The power of a 'super-strong' oracle

- ❑ **A 'paint can'**
  - Sufficient number ($\ge n(n+1)/2$) of super-glue pebbles
  - A sufficiently long ($l \gg |E(G)|$) string

- ❑ Similar to "exploring <u>labeled</u> graphs"
- ❑ Robot can <u>uniquely</u> mark (and recognize) each visited location while exploring
  - no disambiguation needed.
- ❑ Mapping can be efficiently done using DFS, GREEDY, and the like
  - ☑ ***$O(m) \le O(n^2)$*** exploration cost. **Minimum!**

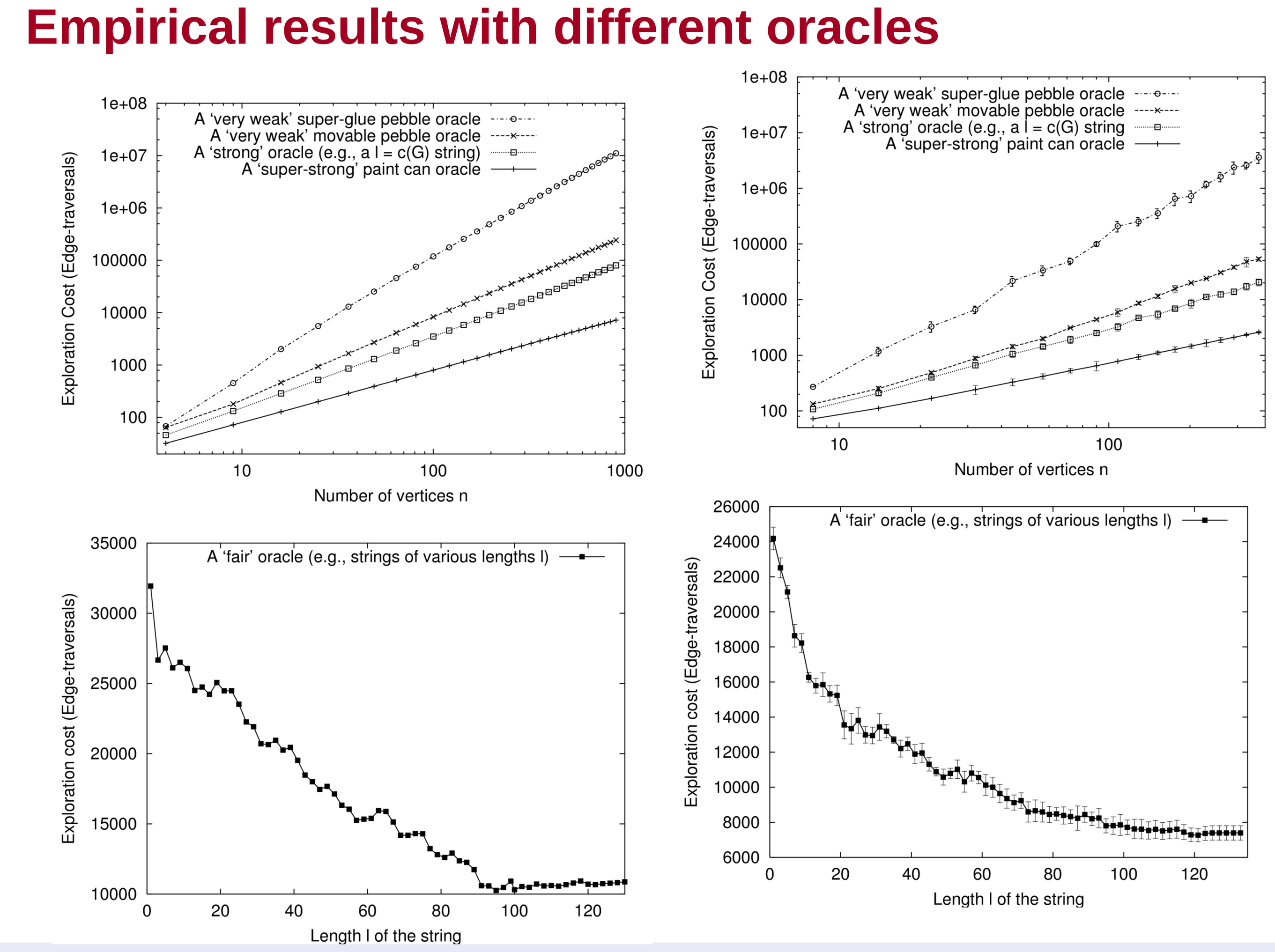
The power of a 'strong' oracle

- ❑ ***n* super-glue pebbles, *n* footprints, $l = c(G)$ string, and the like**
  - Marks all the visited place, but not uniquely
  - Disambiguation is needed
  - Provides additional info that can be exploited to reduce disambiguation cost
  - ☑ ***$O(mn) \le O(n^3)$*** with reduced constant than a 'very weak' oracle

The power of a 'fair' oracle

- ❑ **Less ($\le n$) pebbles, shorter ($l < c(G)$) string, and the like**
  - Marks multiple visited places, but not uniquely
  - Robot may run out of oracles during exploration
  - Explores in phases -- pick up and reuse the oracles
  - ☑ ***$O(mn) \le O(n^3)$.*** Cost varies depending on the amount of the oracles

Empirical results with different oracles



Summary

- ❑ For deterministic mapping of anonymous graphs, an oracle is needed!
- ❑ Mapping is possible with a `very weak' oracle (e.g., a super-glue pebble) has exploration cost ***$O(m^2n) \le O(n^5)$***
- ❑ The minimum exploration cost ***$O(m) \le O(n^2)$*** is possible with a 'super-strong' oracle (e.g. a paint can, a large number of pebbles, a very long string)
- ❑ Other 'medium' oracles are possible with exploration cost ***$O(mn) \le O(n^3)$***

Acknowledgements:

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