Minimal Memory Abstractions

(As implemented for BioWare Corp®)

Nathan Sturtevant

University of Alberta
GAMES Group
February 22, 2007

Talk Overview

- Part I: Building Abstractions
  - Minimizing memory requirements
  - Performances measures
- Part II: BioWare Corp®
  - Implementation
  - Experience

Background

- State-space abstractions have commonly been used to speed search
  - Pattern Databases for heuristics
  - Graph abstractions for pathfinding
    - PRA*, HPA*, etc

Motivation

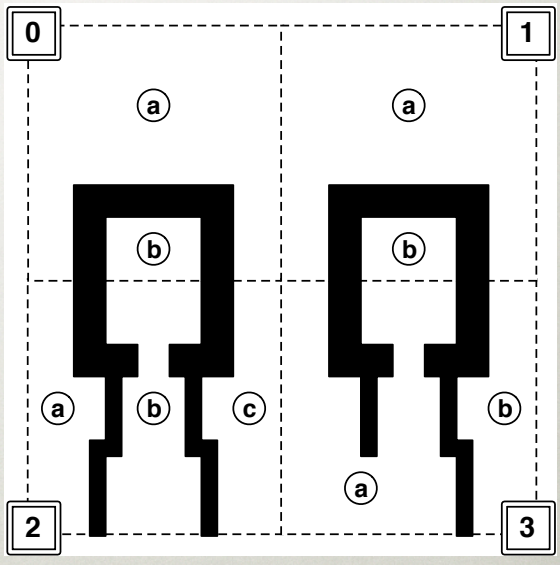
- Games have tight memory budgets
  - ~4MB total memory
  - 1024x1024 or larger maps
    - 1MB per byte per grid cell
- Can we use build an abstraction which minimizes memory usage?

Assumptions

- Grid world
  - No true 3-d movement
- Cells can be blocked / free / weighted
- May be height difference between cells
- Units can move across real-valued space

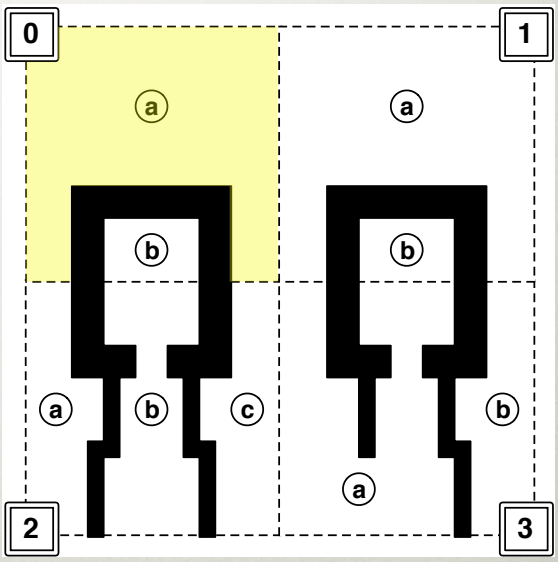
Sectors / Regions

- Divide world into large sectors
  - Fixed size
  - Index implicitly
- Divide sectors into regions
  - Regions entirely connected
  - Regions have a *center* point



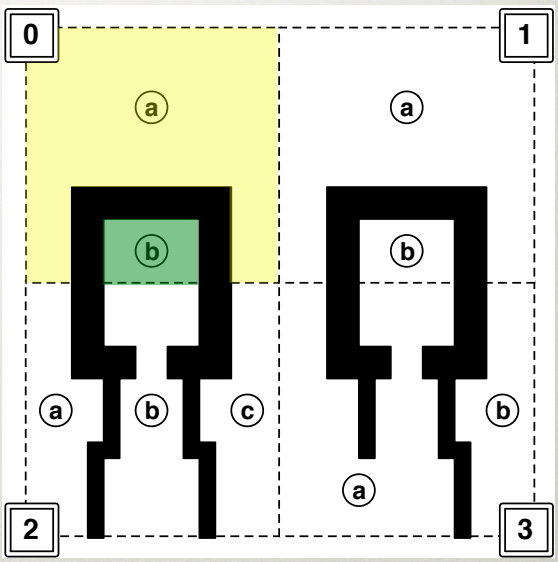
Sectors / Regions

- Divide world into large sectors
  - Fixed size
  - Index implicitly
- Divide sectors into regions
  - Regions entirely connected
  - Regions have a *center* point



Sectors / Regions

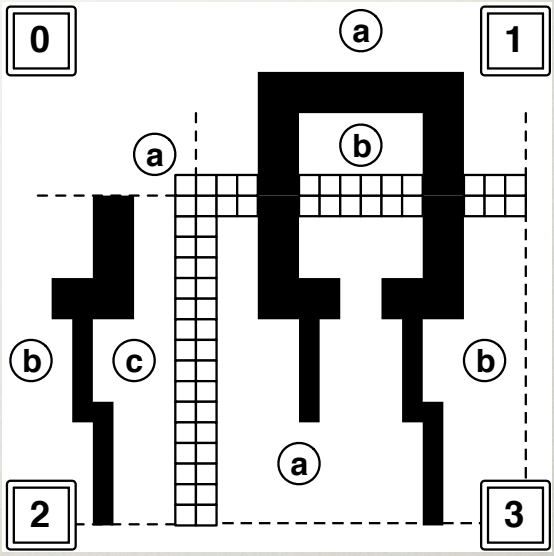
- Divide world into large sectors
  - Fixed size
  - Index implicitly
- Divide sectors into regions
  - Regions entirely connected
  - Regions have a *center* point



6

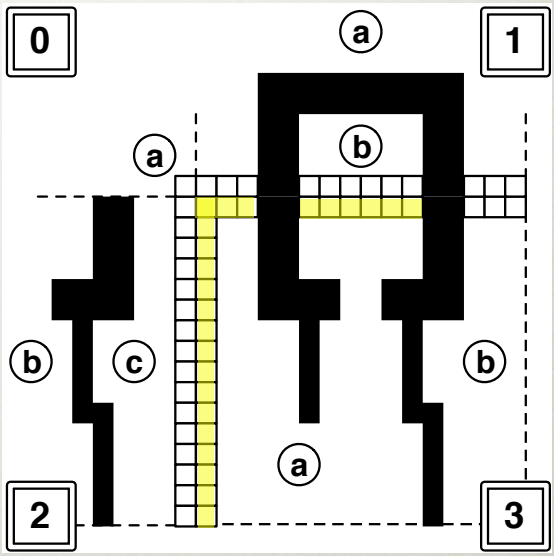
Edges

- Look at borders of regions to determine edges



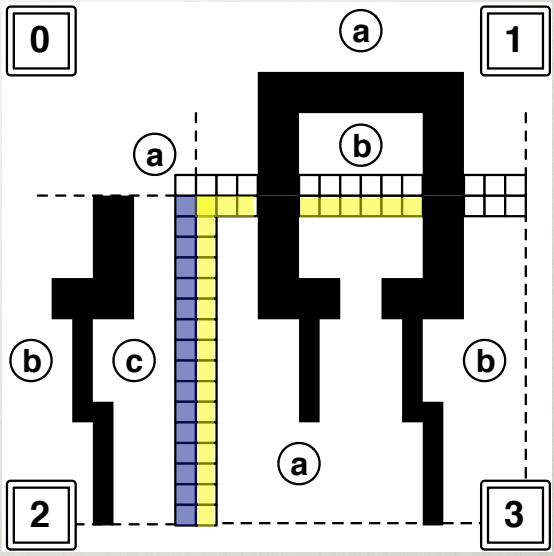
Edges

- Look at borders of regions to determine edges



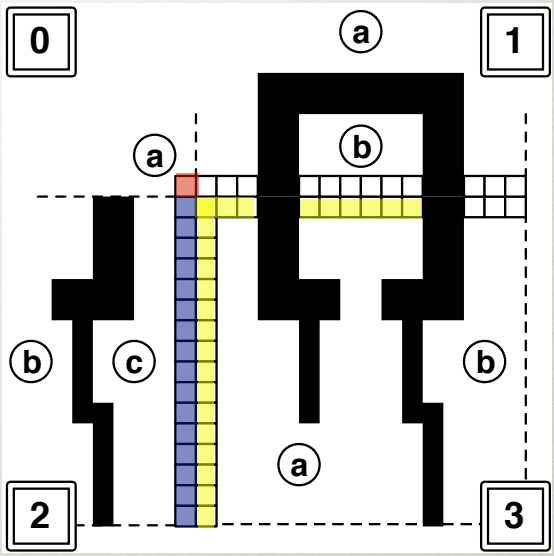
Edges

- Look at borders of regions to determine edges



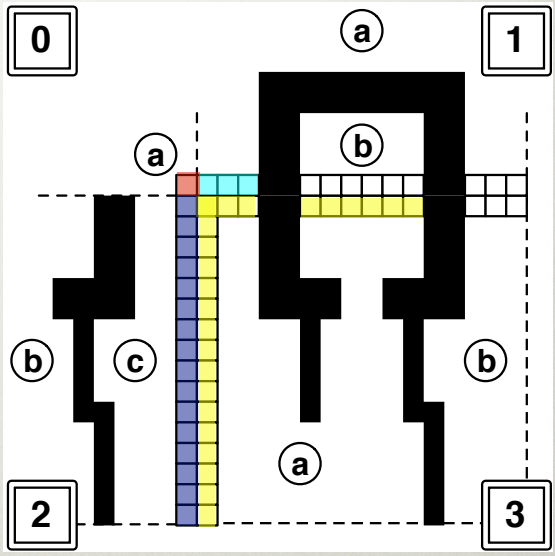
Edges

- Look at borders of regions to determine edges



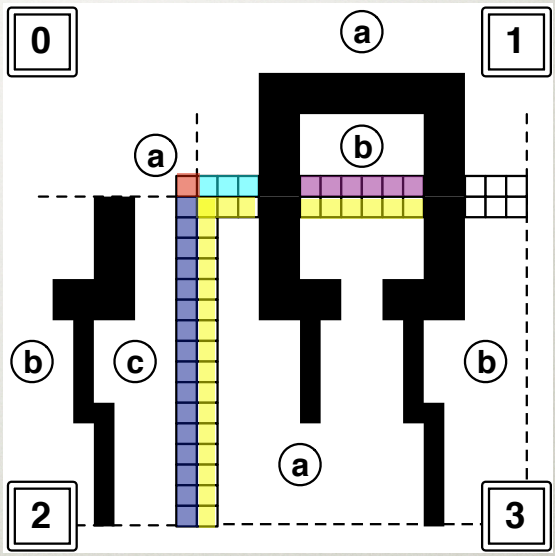
Edges

- Look at borders of regions to determine edges



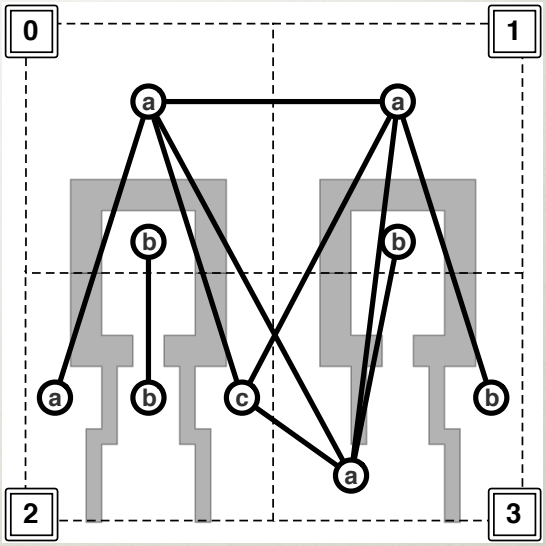
Edges

- Look at borders of regions to determine edges



Abstract Graph

- Original Map:
  - 32x32 = 1024 cells
- Abstract Graph:
  - 9 nodes
  - 10 edges



Memory Usage

- 32 bits per sector
  - Can use less
- 16 bits per region
  - 8 bits per edge
  - 3 bits - direction
  - 5 bits - region
- Skip some regions
- Edges duplicated

32 bits

Sector Data	Example
# Regions	2
Memory Address	0
unused	-

16 bits

Region Data	Example
center	196
# edges	3
center	142
# edges	4
variable-sized edge storage	left:3
	upleft:1
	up:1
	up:2
	up:1

Find Sector/Region

- Begin with x/y location in real world
  - Must find sector/region
- If sector only has 1 region, *done*
- Otherwise do BFS to find region center
  - Can do reverse A* search from region centers
- Avoids pointers*!*

Usage (1)

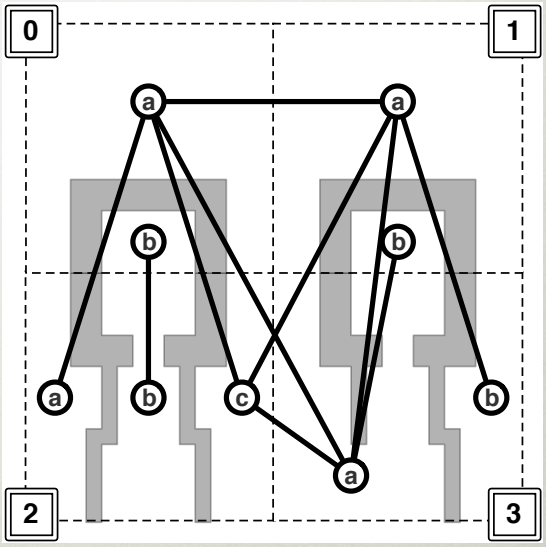
- Find sector/region for starts and goals
- Use A* to find a complete abstract path
- Now we must use the abstract path to guide the search for an actual path

Usage (2)

- Many different methods for using abstract path
- Simplest method:
  - Find path from start to first region
  - Compute path to successive regions
  - Find path from last region to goal

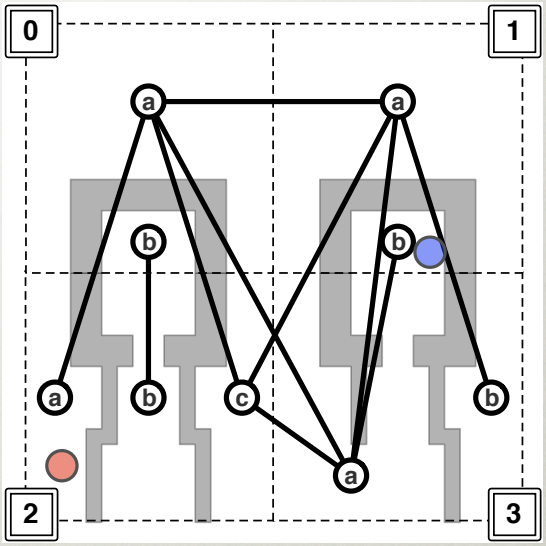
Usage Example

- Find abstract parents
- Find abstract path
- Find real path



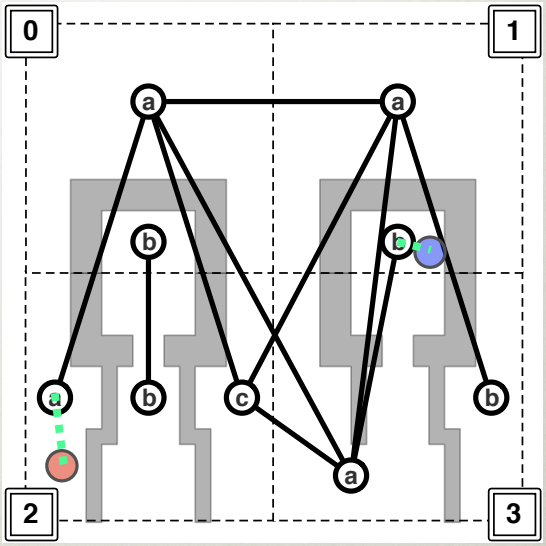
Usage Example

- Find abstract parents
- Find abstract path
- Find real path



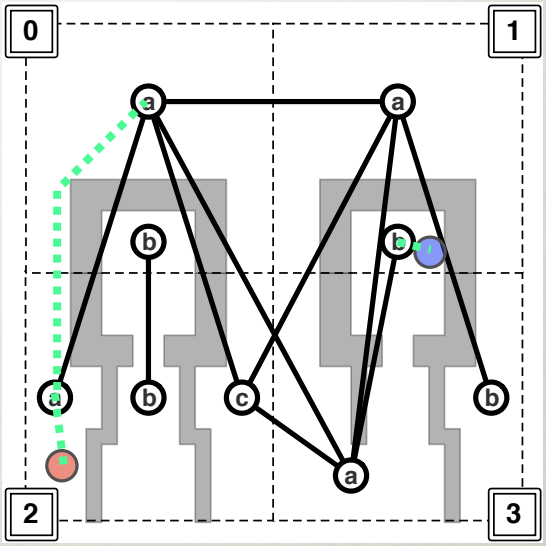
Usage Example

- Find abstract parents
- Find abstract path
- Find real path



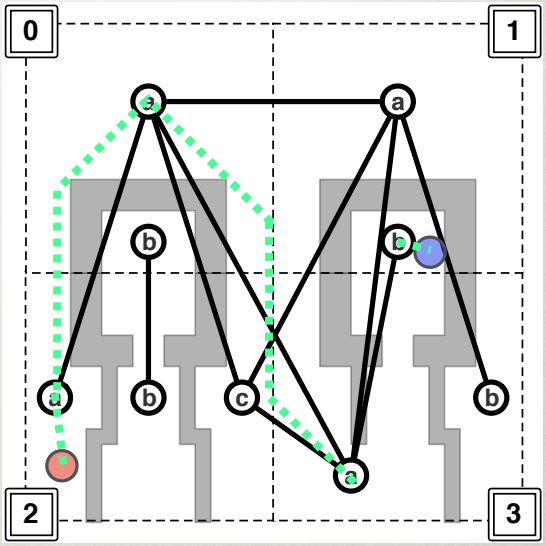
Usage Example

- Find abstract parents
- Find abstract path
- Find real path



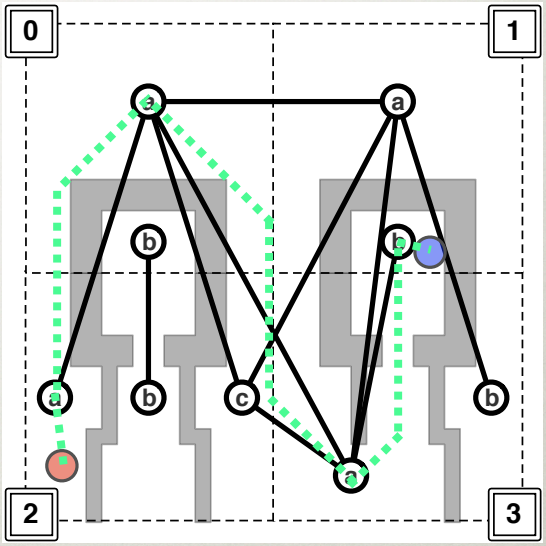
Usage Example

- Find abstract parents
- Find abstract path
- Find real path



Usage Example

- Find abstract parents
- Find abstract path
- Find real path

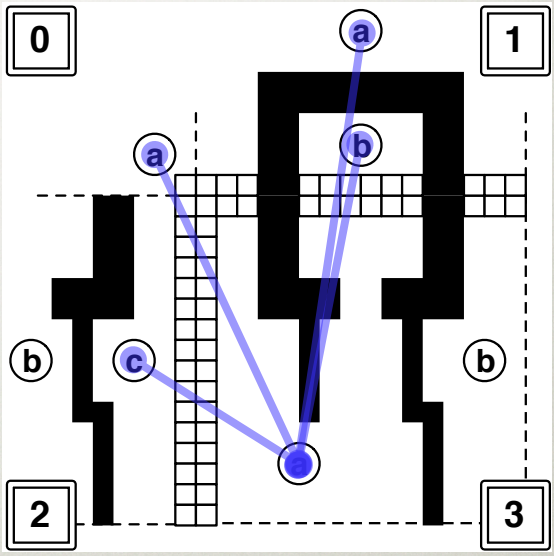


Total Pathfinding Cost

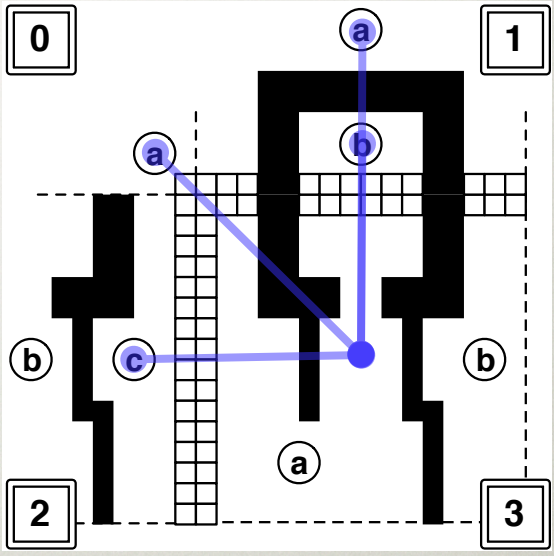
- Abstract planning cost + Refinement
  - Refinement cost depends on obstacles and total path length
  - Abstract planning cost depends on sector size
- For fixed path length, the total work should *depend only on sector size*

Optimizing Region Centers

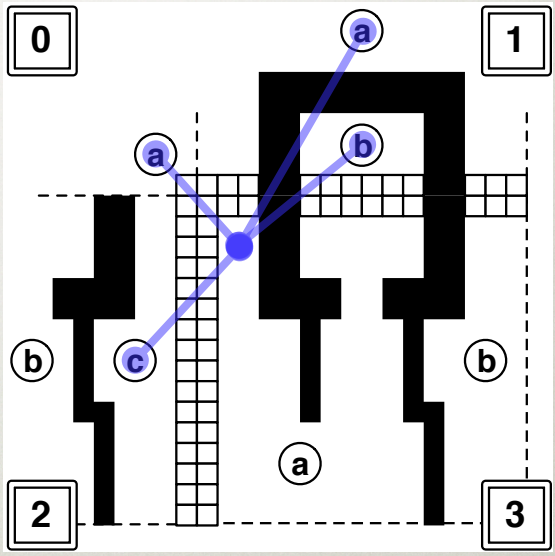
- How to determine the region centers?
- Some locations are much better than others



Optimizing Region Centers



Optimizing Region Centers

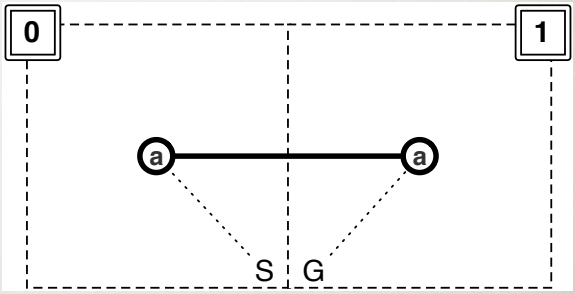


Optimizing Region Centers

- Consider each region independently
  - Measure the A* cost to path between region and all neighbors
  - Choose the region center which minimizes the maximum cost

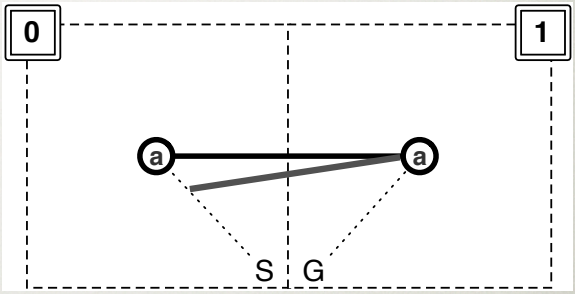
Pathfinding Optimization

- Refinement at start/goal can be inefficient
- Trimming helps
- Skip to next node at start/goal



Pathfinding Optimization

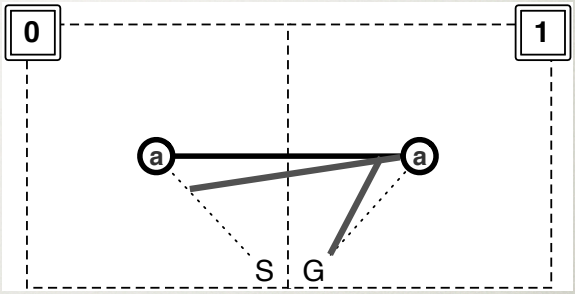
- Refinement at start/goal can be inefficient
- Trimming helps
- Skip to next node at start/goal



19

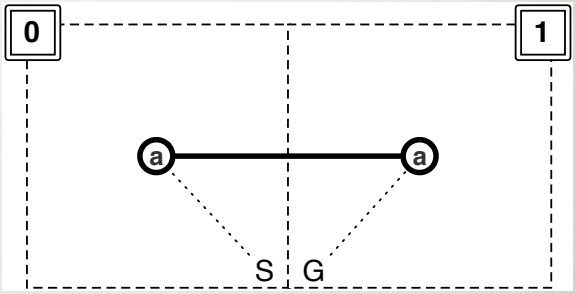
Pathfinding Optimization

- Refinement at start/goal can be inefficient
- Trimming helps
- Skip to next node at start/goal



Pathfinding Optimization

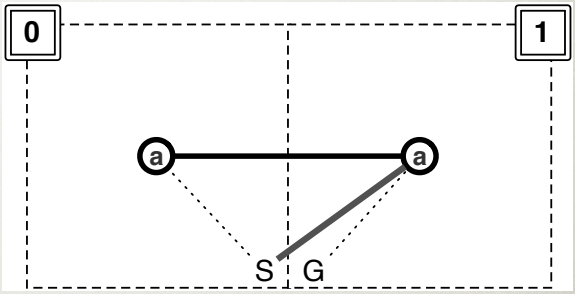
- Refinement at start/goal can be inefficient
- Trimming helps
- Skip to next node at start/goal



19

Pathfinding Optimization

- Refinement at start/goal can be inefficient
- Trimming helps
- Skip to next node at start/goal



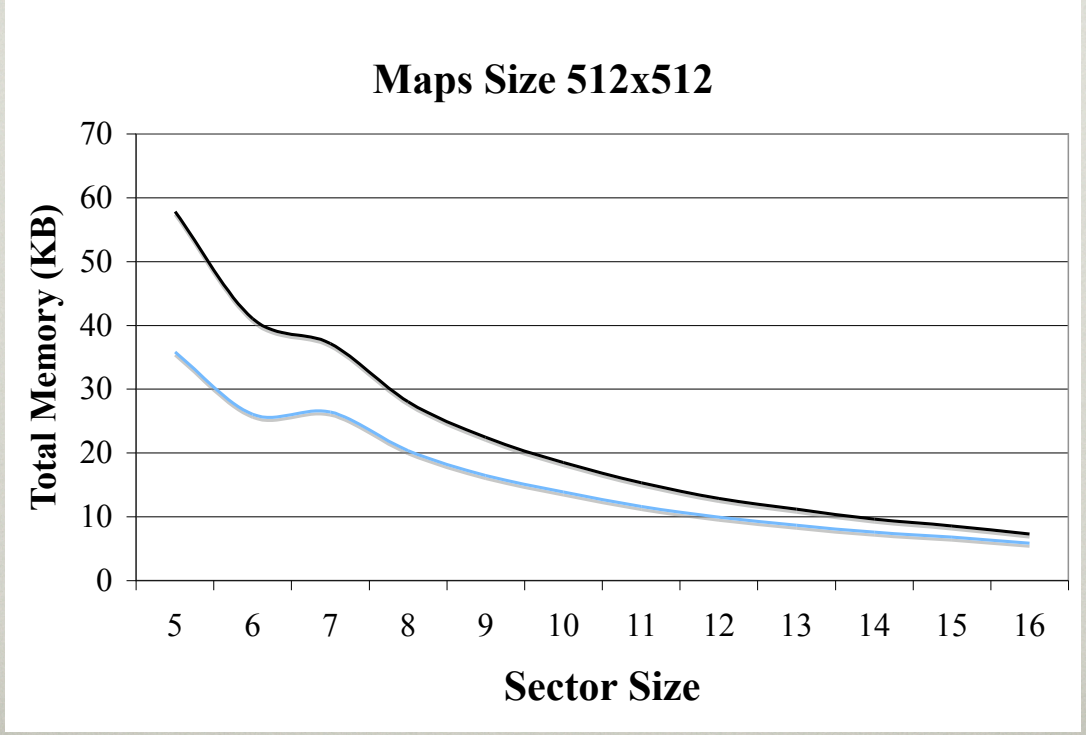
Experimental Results

- 93,000 paths over 120 maps
- Maps scaled to 512x512
- Paths in 128 buckets length 1…512
- Measure:
  - Total cost
  - Incremental cost

Memory Usage

- How does the memory usage scale with sector size?
  - How much memory can be saved with simple compression?
  - Don't store "default" regions
    - 1 region, 8 neighbors

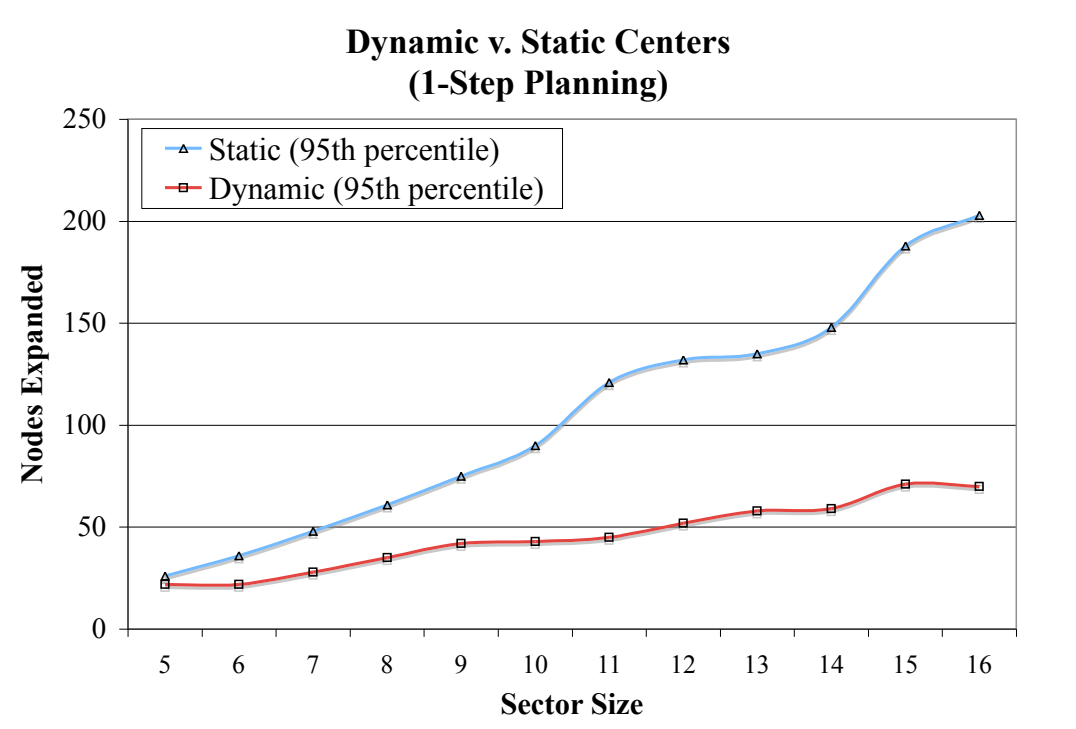
Memory Usage



Dynamic Region Centers

- Is there a gain to dynamically optimizing region centers?
- Measure 95% work done in one-step path refinement

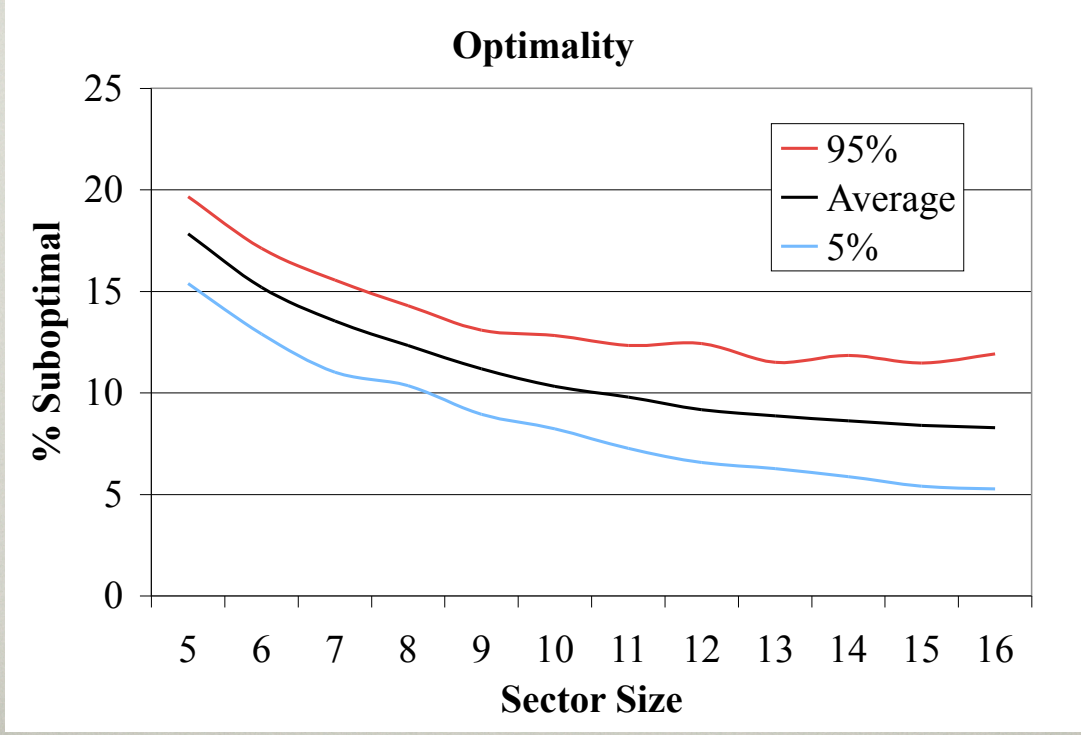
Dynamic Centers



Optimality

- Paths will not be optimal
  - Special cases for start/goal help a lot
- Smoothing will be applied as a post-processing step (not measured)

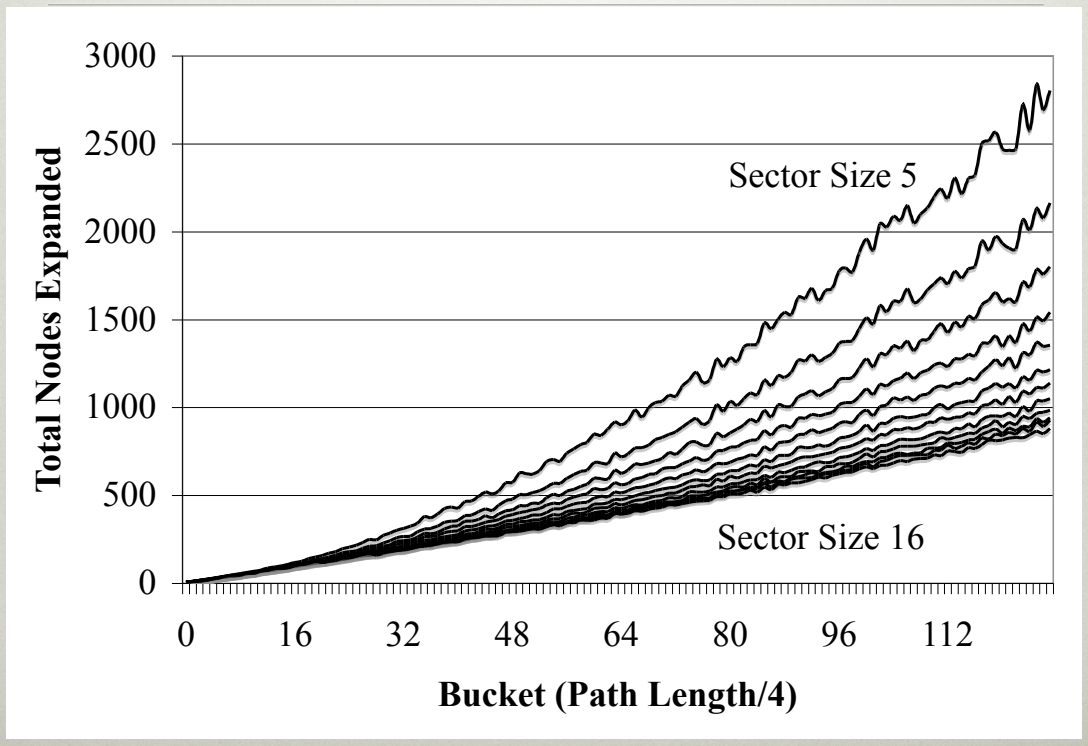
Optimality



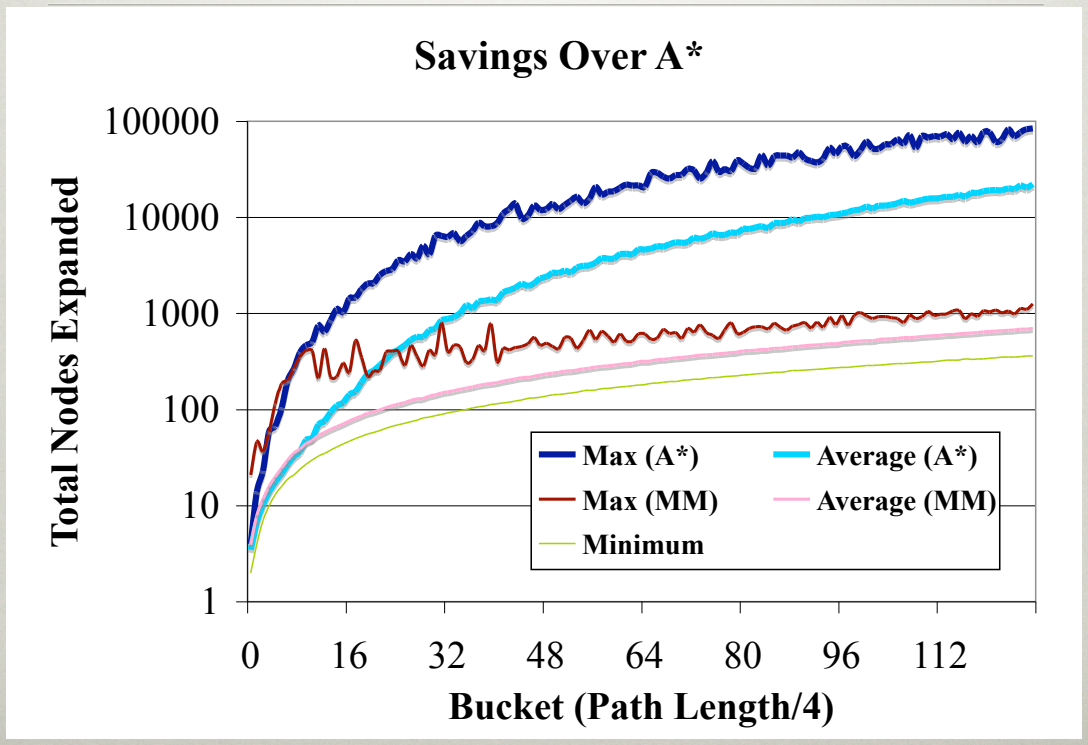
Total Work

- Sum of work needed:
  - Find parents
  - Find abstract path
  - Refine low-level path
- Compare to A*

Total Work



Total Work v. A*



Implementation

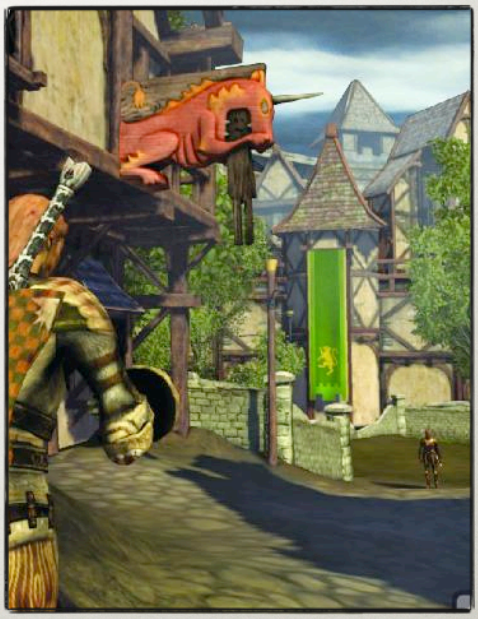
- 2 weeks:
  - Implement abstraction
  - Implement pathfinding
  - Initial testing
  - Met pathfinding requirements

Observations

- Cannot be an expert in one thing
- Get it "good enough"
- Both more and less rigorous testing than expected
- Great people

Future

- Continuing work:
  - Smoothing
  - Placeables



More Info

- http://dragonage.bioware.com/
- http://www.1up.com/do/gameOverview?cId=2019479
- http://www.1up.com/do/previewPage?cId=3155733

Thanks