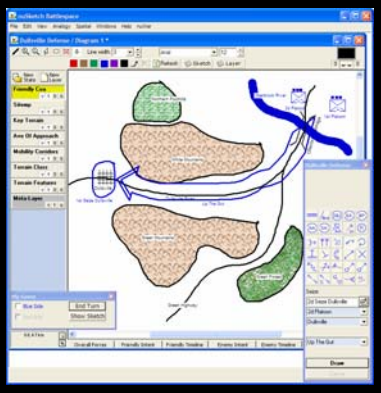
Qualitative Spatial Reasoning about Sketch Maps

Kenneth D. Forbus Jeffrey Usher Vernell Chapman

Qualitative Reasoning Group, Northwestern University



Presentation by Michael Hoffman

Qualitative Spatial Reasoning about Sketch Maps

- Introduction
  - spatial representation used in many geospatial reasoning tasks

  - Used to reason through a problem, not for conceptual design process
  - Typically drawn by hand on paper

Qualitative Spatial Reasoning about Sketch Maps

- Introduction
  - specific geospatial domain, *battlespace reasoning*
  - *Warfare*
    - Complex and important task
    - Requires coordinating an array of various units, equipment
    - Achieve goals in situations with great uncertainty and danger
    - Terrain effects movement, provides cover and concealment, and effects the operation of sensors

  Thus, geospatial reasoning must provide a role in generating and reasoning about battle plans

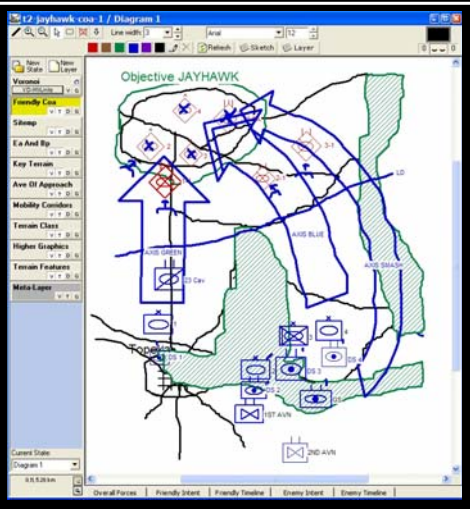
Qualitative Spatial Reasoning about Sketch Maps

- Introduction
  - Problem with current systems
    - Commanders don't want to use mouse and menus
    - Want to use sketch and interact with their people
  - Solution…

    nuSketch Battlespace (nSB)

Qualitative Spatial Reasoning about Sketch Maps

- Overview of nSB
  - Avoid recognition issues by using clever interface design
  - Focus on richer visual and conceptual understanding of what is sketched
  - Two Systems have been developed:
    - nuSketch Battlespace (nSB): for battlespace reasoning
    - Sketch Knowledge Entry Associate (sKEA): general-purpose knowledge capture



Qualitative Spatial Reasoning about Sketch Maps

- large knowledge base concerning specialized military concepts
- Allows user to specify conceptual information
  - Types of entities
  - Timing information
  - Intent of actions
- Also
  - Sketch terrain
  - Specialized areas
  - Paths (engagement areas, axes of advance)
  - Position units
  - Assign tasks and reasons for doing them

Qualitative Spatial Reasoning about Sketch Maps

- Representing Glyphs and Sketches
  - Basic unit in a sketch is a *glyph*, every glyph has *ink* and its *content*
    - Ink consists of one or more polylines (points/width/color)
    - Content is a conceptual entity (the kind of thing that the glyph is representing)
    - [example] if user drew a mountain range, there would be an entity created to represent the glyph itself and an entity to represent the mountain range.

Glyph bar -

Qualitative Spatial Reasoning about Sketch Maps

- Type of glyph content affects the interpretation of its spatial properties
- [example] spatial extent representation of glyphs
  - Spatial extent of mountains and lakes are taken to be the spatial extent of that terrain feature.
  - Spatial extent of military unit is ignored, since the size of such glyphs has nothing to do with its footprint on the ground
    - centroid is used in spatial reasoning
  - Spatial extent of paths (roads and rivers) have one-dimensional extent, where width is not tied to the width of the line but is specified by special gestures

Qualitative Spatial Reasoning about Sketch Maps

- Three types of Spatial Relationships
  - Types of Qualitative topological relationships
    - 2 glyphs can be disjoint (DC), touching (EC), or inside one another (TPP, NTPP)
  - Voronoi relationships
    - Diagram consisting of edges that are equidistant from a pair of points
    - Constructs obstacle and cost diagrams and the quad tree representation used in path-finding
  - Positional relationships
    - Provide position and orientation with respect to a global coordinate system

Qualitative Spatial Reasoning about Sketch Maps

- Position-finding
  - Two important constraints in military spatial reasoning:
    - fields of fire (i.e., what can someone's weapon see?)
    - Observations (i.e., what can someone see?)
  - terrain features
    - Mountaints - block weapons, and thus provide cover
    - Forest – block visibility, and thus provide concealment

…finding these positions is an important subtask in military planning

Qualitative Spatial Reasoning about Sketch Maps

[concealment example]

- Trying to find all regions where someone could hide from us
- Table indicates what kinds of terrain regions units can hide in
- (**V**) - For each unit on our side, a new polygon is constructed by ray-casting to represent the region that is visible from that unit
- (**W**) – polygons that result from subtracting out places where units cannot be (e.g., in lakes)
- (**W – V**) – places where an enemy could hide

Terrain Type	Concealed?	Cover?
Mountains	Yes	Yes
Hills	Yes	Yes
Open/rolling hills	No	Yes
Forest	Yes	Partial
Jungle	Yes	Partial
Desert	No	No
River	No	No
Bridge	No	No
City	Yes	Yes
Road	No	No

- Fields of fire and cover, are computed similarly, using cover constraints and weapon ranges

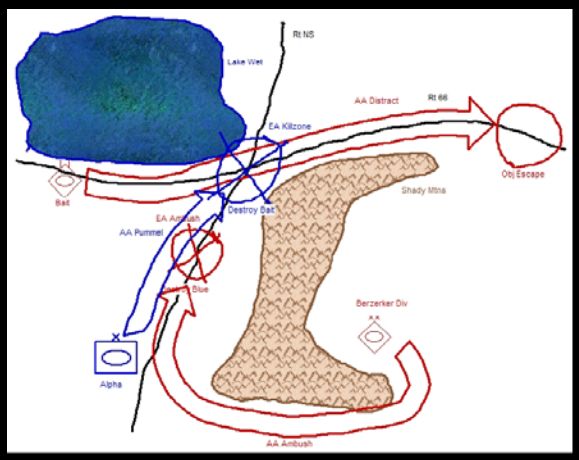
Qualitative Spatial Reasoning about Sketch Maps

- Path-finding
  - Obstacles depend on type of unit moving
    - [example] Forests are considered untrafficable for vehicles but trafficable by infantry
  - Cost of movement depends on type of terrain
    - [example] Takes longer for infantry to move through a swamp than through a desert
  - Divide space into regions
    - UR, “go” – unrestricted terrain
    - R, “slow go” – restricted terrain (high cost)
    - SR, “no go” – severly restricted terrain (obstacles)

Terrain Type	Armor	Infantry
Mountain	SR	R
Hills	R	UR
Open/rolling hills	UR	UR
Forest	SR	R
Jungle	R	R
Desert	UR	UR
River	SR	SR
Bridge	UR	UR
City	R	UR
Road	UR	UR

Qualitative Spatial Reasoning about Sketch Maps

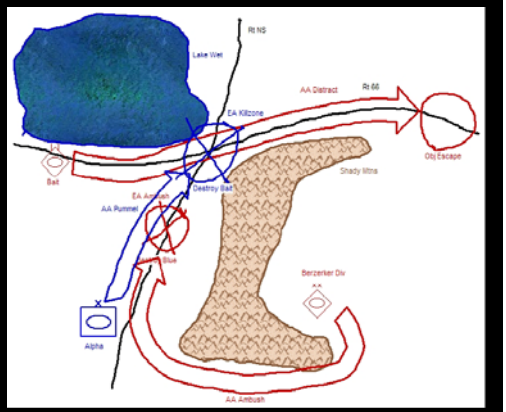
Example: Hypothesizing enemy intent by analogy



Qualitative Spatial Reasoning about Sketch Maps

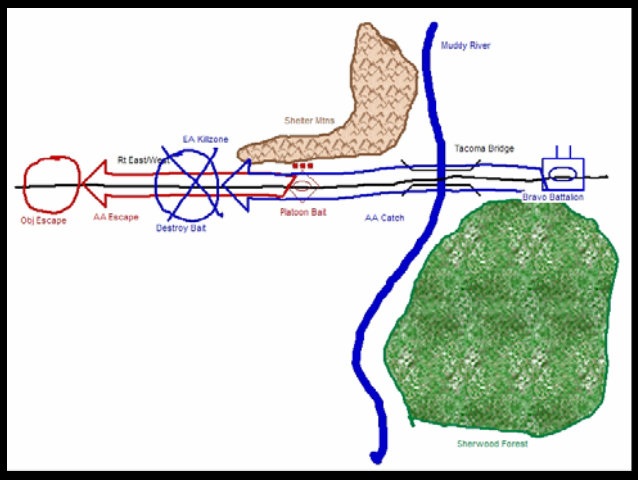
Example: Hypothesizing enemy intent by analogy

1. unit Bait is trying to escape Alpha Battalion which is planning to destroy it at EA killzone
2. Berserker Division (hiding behind the mountain range) attacks Alpha from the rear as Alpha goes after Bait, causing considerable damage
3. The ambush is successful because the attacker was concealed and could travel to an engagement area on Alpha's path



Qualitative Spatial Reasoning about Sketch Maps

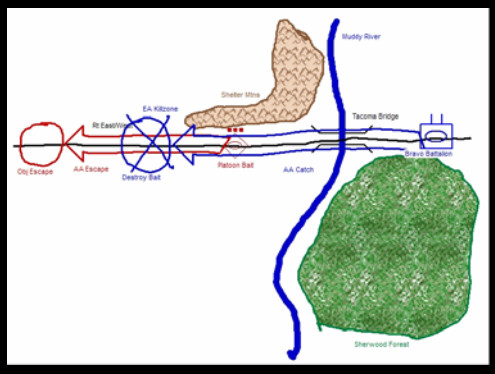
Example: Hypothesizing enemy intent by analogy



Qualitative Spatial Reasoning about Sketch Maps

Example: Hypothesizing enemy intent by analogy

1. Your unit, Bravo, sees enemy unit Bait trying to escape, and you are tempted to go after it
2. Having heard about what happened to Alpha, you are worried.
3. Using nSB, you can ask for hypothesized enemy tasks about the current situation based on the precedent sketched state

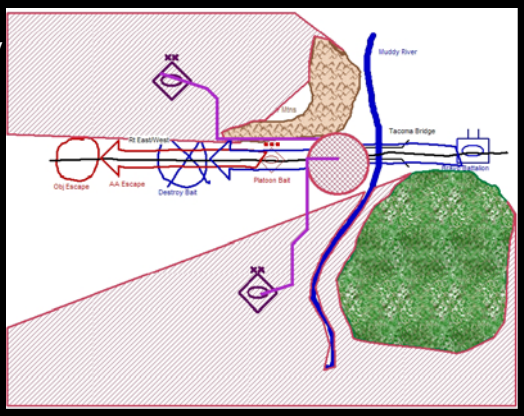


Qualitative Spatial Reasoning about Sketch Maps

Example: Hypothesizing enemy intent by analogy

Answer

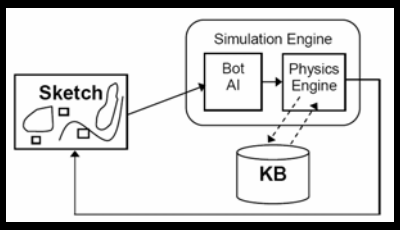
- There are 2 places that an enemy unit might be hiding, to carry out an ambush similar to what happened before
- The pink circle represents the engagement area, the regions represent possible starting locations for Red, and the purple lines indicate hypothetical paths



Qualitative Spatial Reasoning about Sketch Maps

Example: Hypothesizing enemy intent by analogy

- Structure-Mapping Engine (SME) is the cognitive simulation of analogical matching
  - Backed by considerable psychological evidence
- nSB runs SME on both visual and conceptual information
- SME derives set of candidate inferences about the current situation based on the comparison
- Next, the set is searched to see if there is a hypothesized task which acts on a blue unit
  - Such a task represents something the enemy might be doing



KB = "knowledge base" [Sketch Knowledge Entry Associate (sKEA)]

Qualitative Spatial Reasoning about Sketch Maps

Example: Hypothesizing enemy intent by analogy

- If such a task is found, a new entity is created to represent that task, and SME is re-invoked to mine the analogy further
- After all info about the hypothetical task is mined from the analogy, the system will determine if this task is plausible
- (current system) ignores factors such as relative combat power
  - Solve for locations and paths involved in the task to see if we can find positions and a path that satisfy the task's contraints

Qualitative Spatial Reasoning about Sketch Maps

- User Experience
  - AlphaTech and Teknowledge
  - BBN's CADET system – if active-duty military personnel could successfully create COAs
    - Result: 3-5x faster w/o degradation in plan quality
  - DARPA's Rapid Knowledge Formation program
  - DARPA's Command Post of the Future program
  - KRAKEN system from the Cycorp team combined with the SHAKEN system from the SRI team
- Overall generals were able to analogies between battlespace states within an hour of sitting down with the software for the first time.

Qualitative Spatial Reasoning about Sketch Maps

- Future Work [3 key problems to address]
  1. Optimization within constraint solutions (e.g., picking optimal combinations of starting and ending positions and paths)
     - Important for supporting war-gaming, where one wants to see how a plan survives the best that an opponent might throw at it
  2. Sketch retrieval (i.e., automatically finding precedents to be used in generating enemy intent hypotheses and COAs)
  3. Moving beyond *blob semantics* (i.e., using more info about glyph shapes in matching and retrieval)