Towards a Semantic Spatial Model for Pedestrian Indoor Navigation

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REWERSE© reasoning on the web

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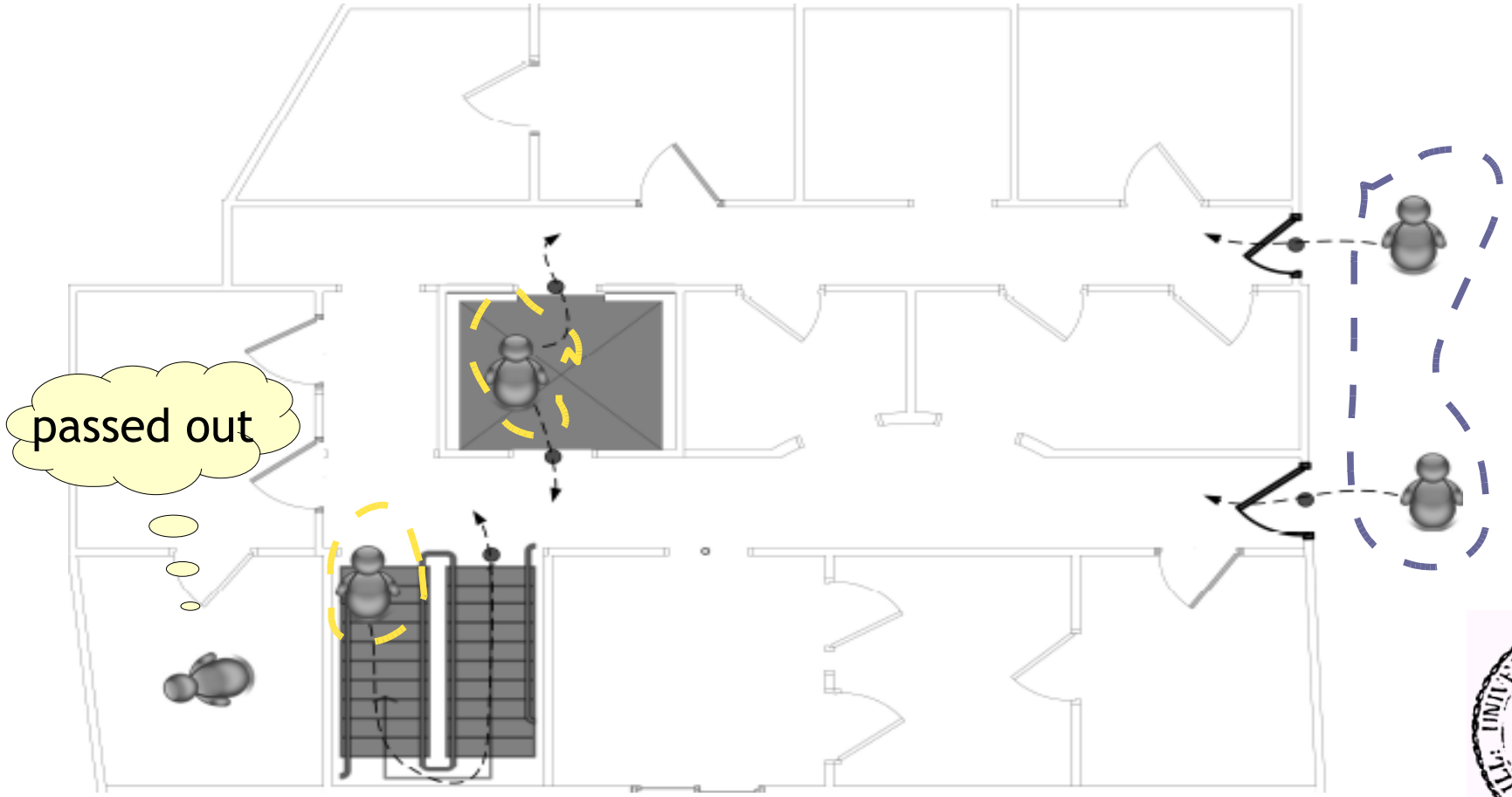
Outline

- Motivation
- Problem / Scope
- The Proposed Model
- Outlook

Motivating Scenario

- Emergency: outside → inside (and vice versa)



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Problem: Wayfinding

- (self-)localisation, specify destination
  - "*Where* is room 1.02?" ; "Where is the *next* printer?"
  - spatial queries as known from LBS/GIS community

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➡ positioning systems vs. *symbolic* locations

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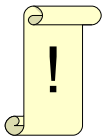

- determine path - "*How* to get there?"
  - flavored by **AI**, **computational geometry**: planning & graph search algorithms

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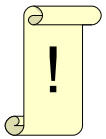

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  - ➡ optimal vs. approximate solutions; different criteria

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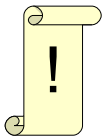

- determine path - "*How* to get there?"
  - optimal vs. approximate solutions; different criteria

- communicate result/plan
  - verbal
    - "..go *along* the corridor *until* the end.."
    - "..take the second door on your *right*."
  - or simply display on map

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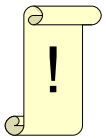


- determine path - "*How* to get there?"
  - optimal vs. approximate solutions; different criteria

- communicate result/plan
  - refer to structure, not just mere sequence of places
    - "..go *along* the corridor *until* the end.."
    - "..take the second door on your *right*."

  ➡ unambiguous, *followable* route instructions

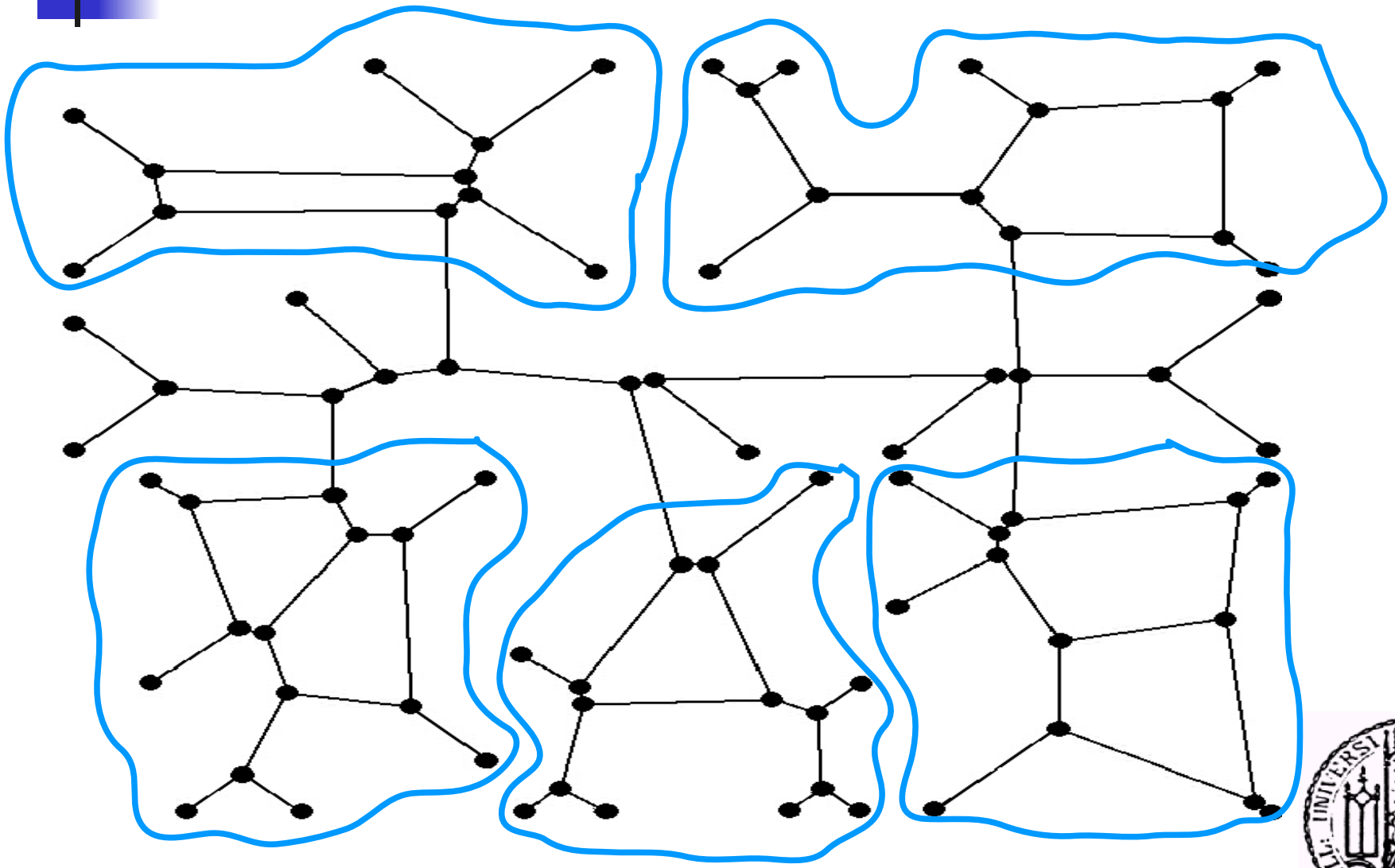
Pedestrian Assistance

- More *challenging* than other domains (car navigation):
  - *free* movement in open space, not constrained to network - rather 3D environment
  - arguably many different ways of representation:
    - Generalised Voronoi Graph
    - Visibility Graph

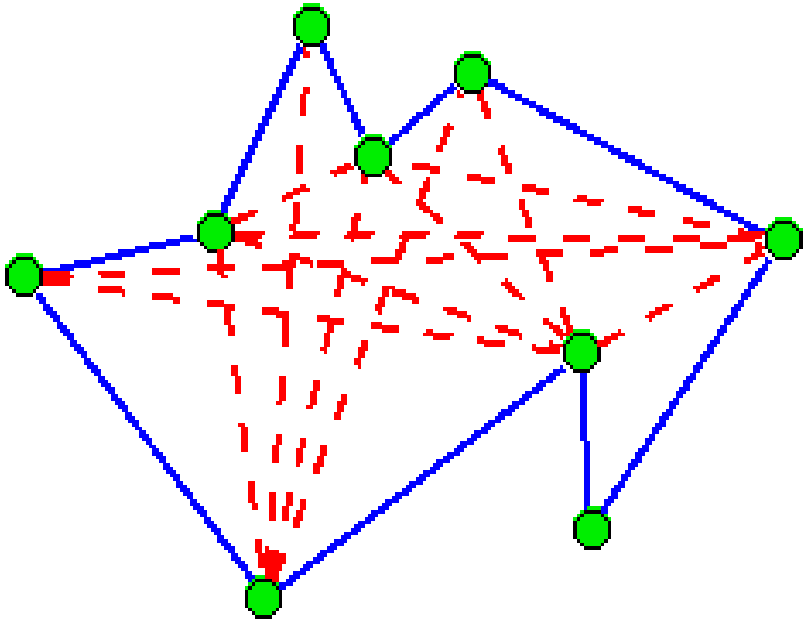
    } *overlays* a region
    - Region Adjacency Graph

    } *coarser!*
  - both *allocentric* & *egocentric* perspective

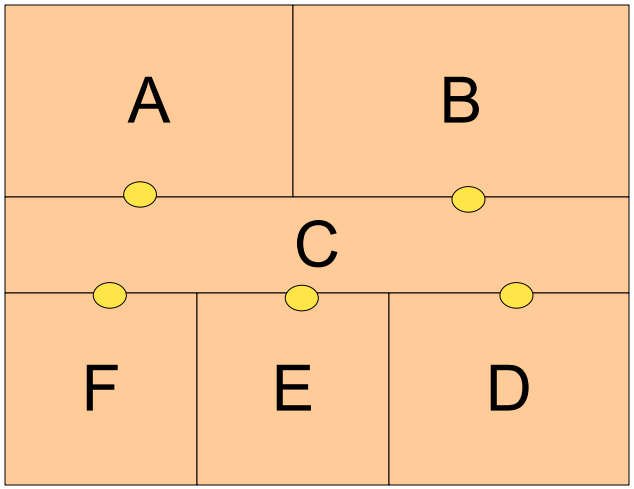
Generalized Voronoi Graph

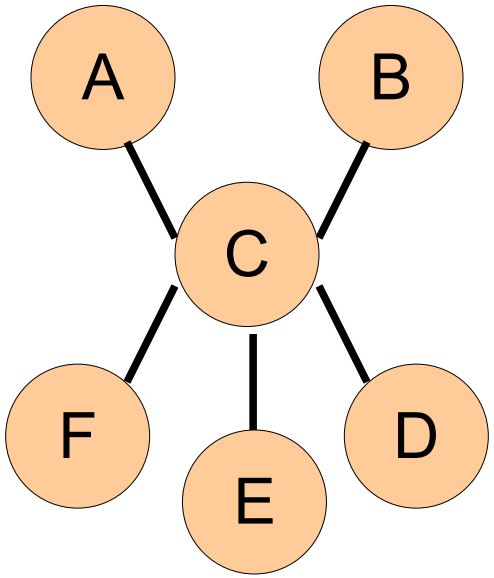


Visibility Graph



Region Adjacency Graph





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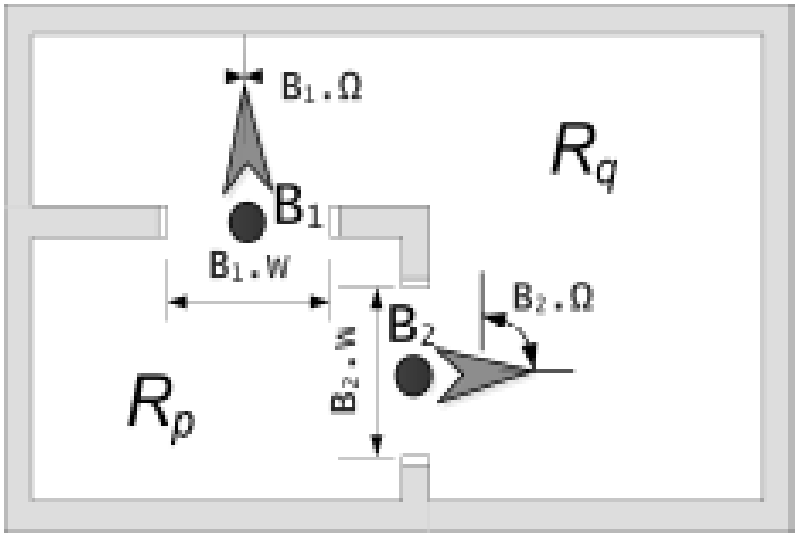
Our Approach

- using a *conceptual* model (schema):
  - higher degree of abstraction (topology)
  - further *annotation* allowed (non-spatial, function)
  - suitable for all three stages of **wayfinding**
  - fill model: *derive* instances from geometric data (floor plans), automate process
  - **hybrid**: maintain reference to full geometry

Conceptual Model

- Two primitives (*typed*)
  - *spatial region*
    - nesting/hierarchy
      - composite vs. leaf region
    - adjacency defined by..
  - *boundary node*
    - connects *two* spatial regions, on boundary
    - local waypoint:
      - w = width
      - Ω = orientation at *entry*



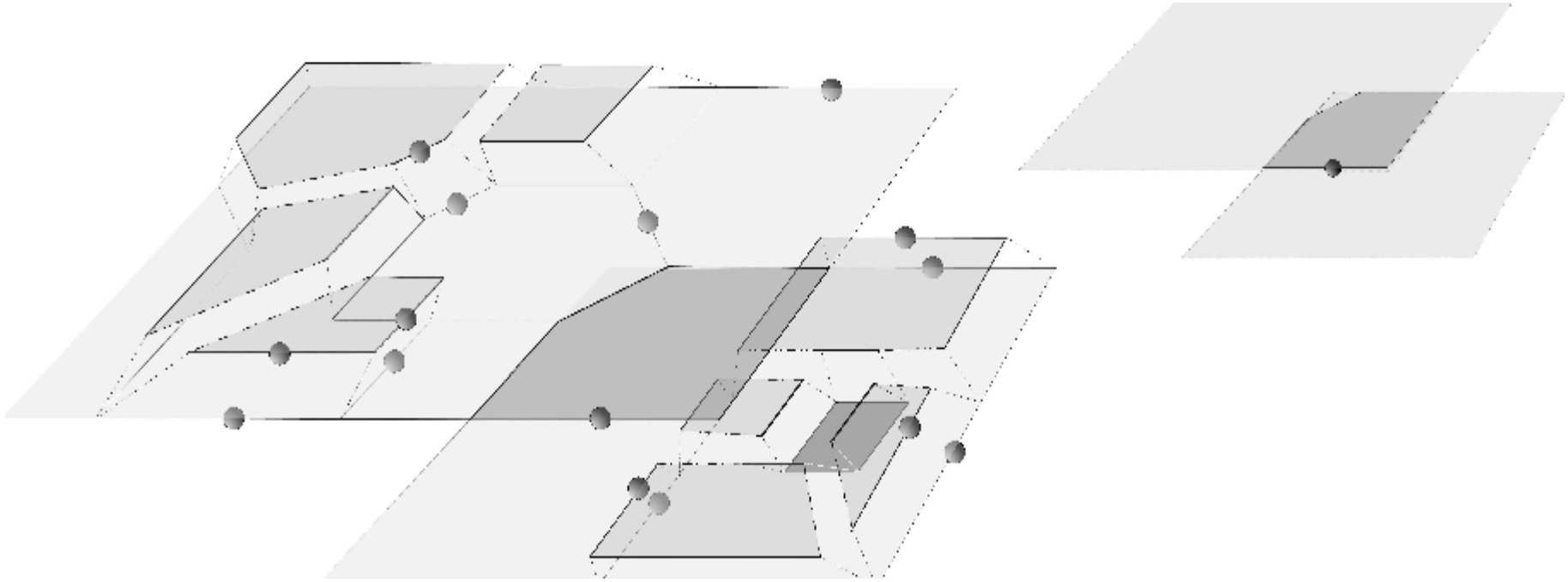
Two Kinds of Boundaries

- *Hard* Boundaries
  - explicit - floor plan: walls, obstacles, ..
  - **passability**: enter/leave *only* at boundary nodes (door, opening ..)
  - **visibility**/preview – glass door/wall
- *Soft* Boundaries
  - implicit - "*around the corner*"
  - often experienced unconsciously

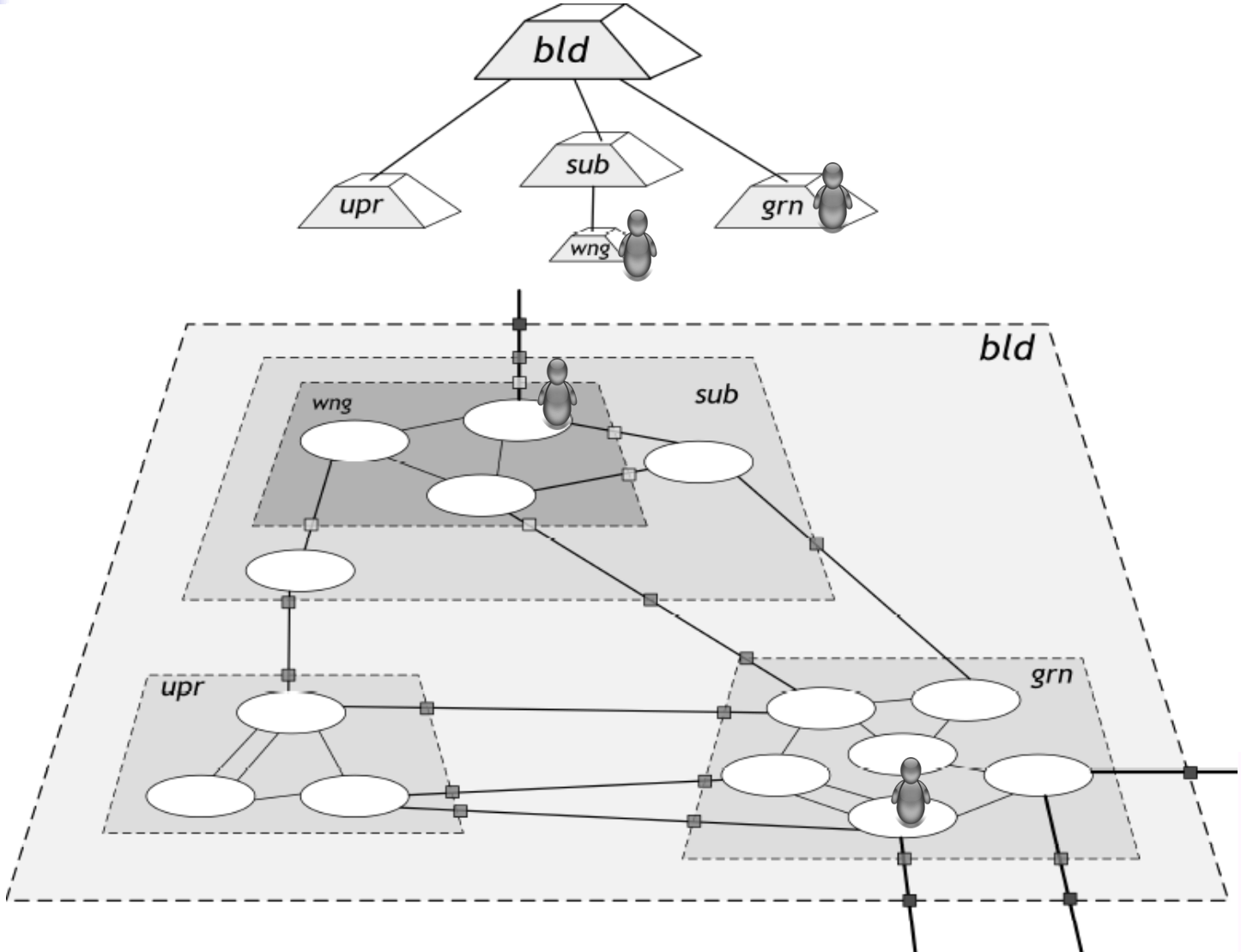
↳ *fuzzy*, difficult to assign distinct location

Part of + Connected

- clusters of *path-connected* regions



A Multi-Level Hierarchy

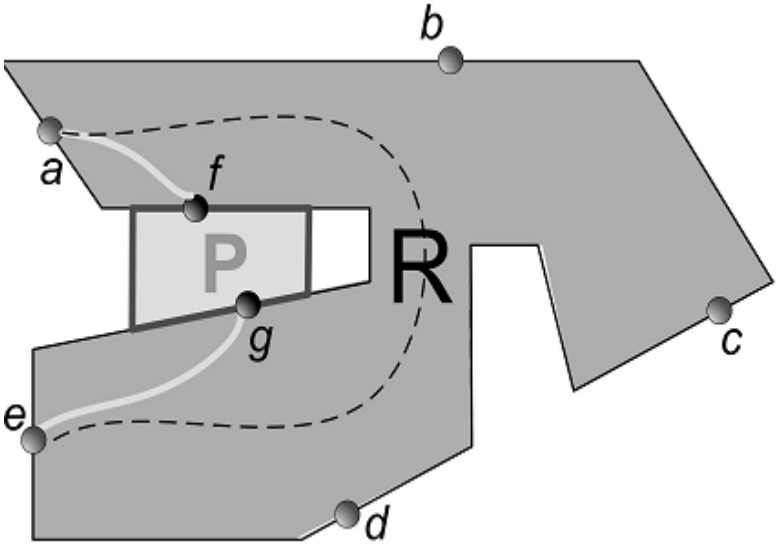


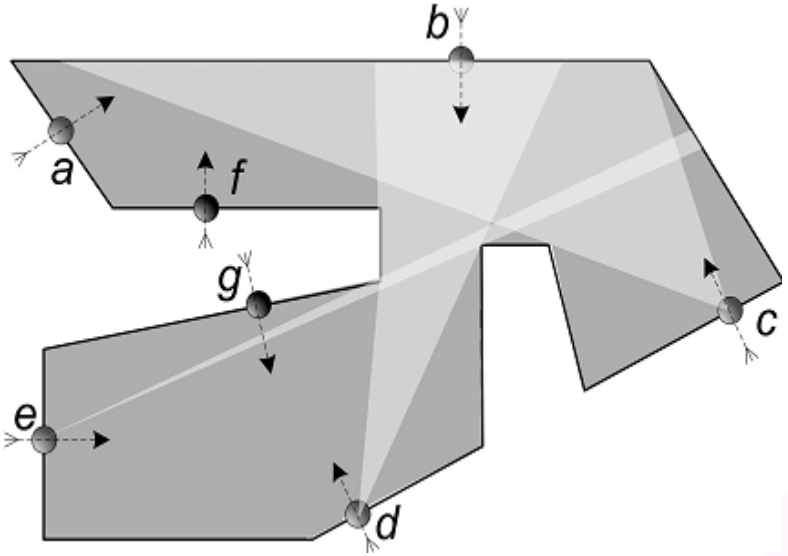
Planning, thought of hierarchically

- use knowledge about structure for planning ⇨ define sub-goals
  - "In order to reach room D1.02, I have to reach wing D."
  - "Wing D is on the first floor, so I have to get there *first*."
- heuristic – guide search, reduce search space
- *refinement* search vs. *precompute* all-pairs
- smallest common ancestor

Problematic Case: Navigation Inside Non-Convex Regions

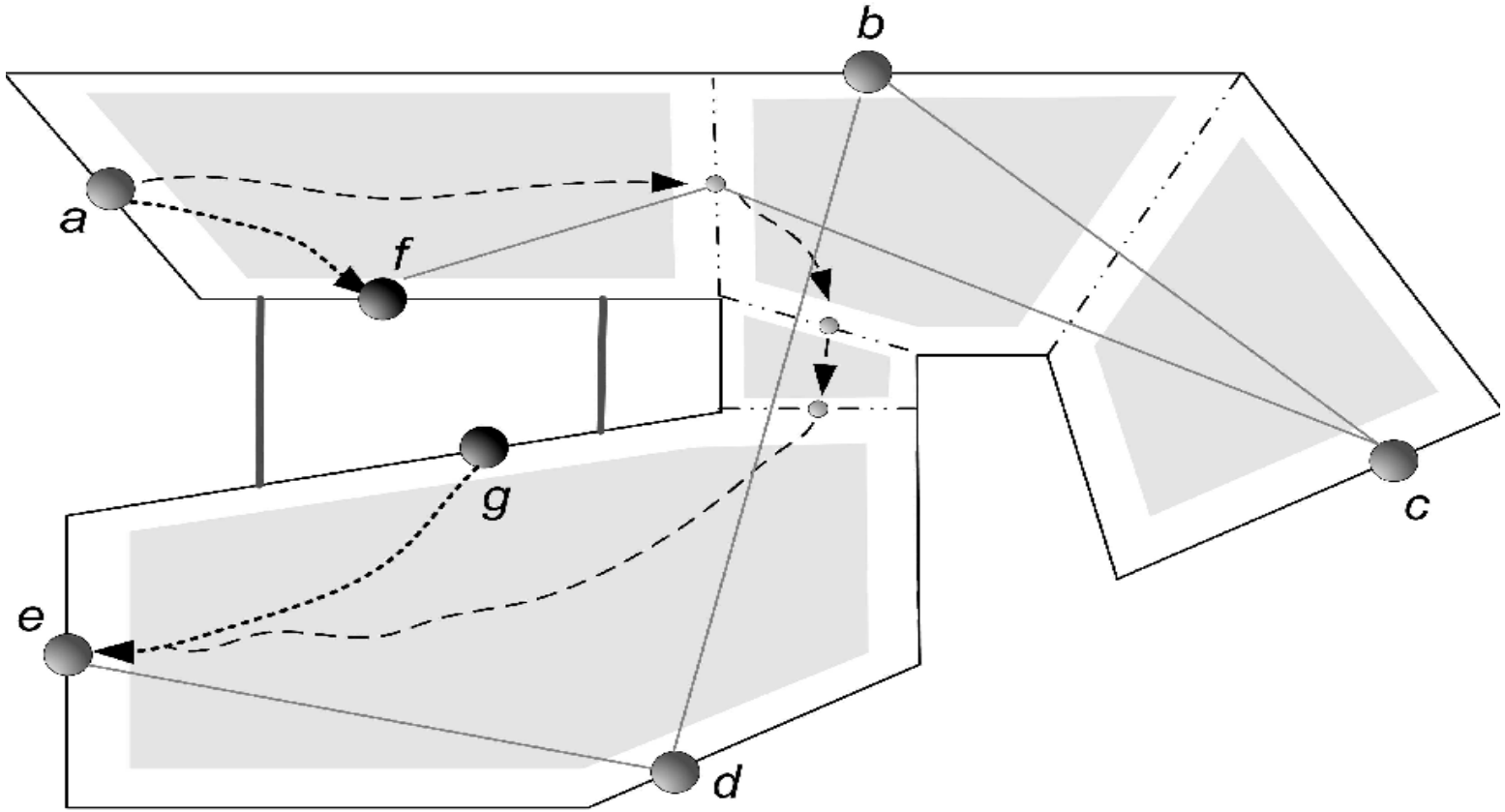
- path inside region may be longer than through exterior
- orientation + visibility for route descriptions





Solution: Convex Decomposition

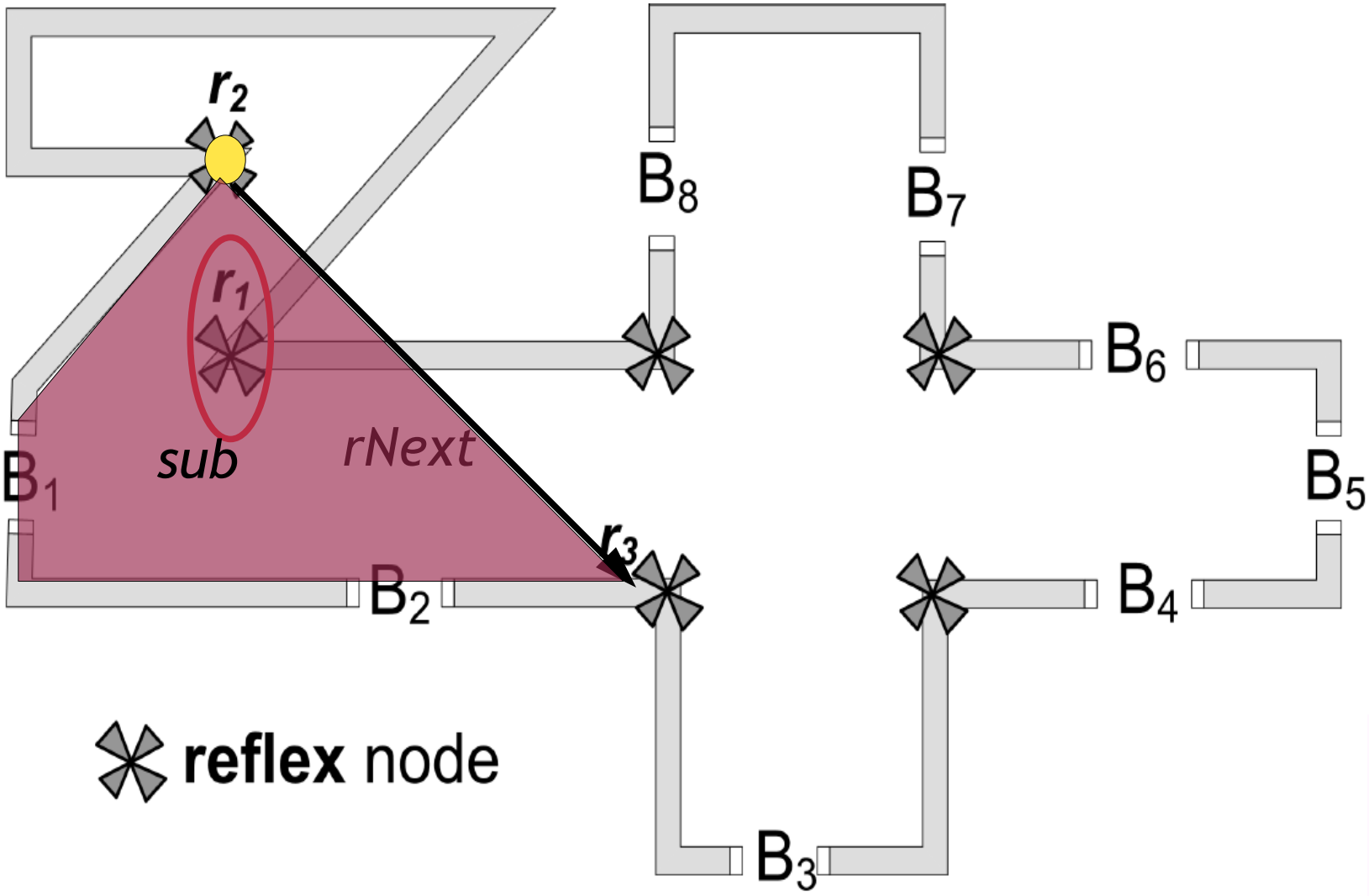
Cell = convex space: mutual visibility +
shortest possible path implicit ➡ for free!



Convex Decomposition

- non-classical (not triangulation, ..)
- idea: use natural landmarks
  - (non-convex) corners, corners of obstacles
  - problem: determine *salience*
    - might use convex hull as reference
    - tolerance: angles slightly greater than 180°
- closure of non-connected spaces
  - smaller distances preferred

A First Algorithm



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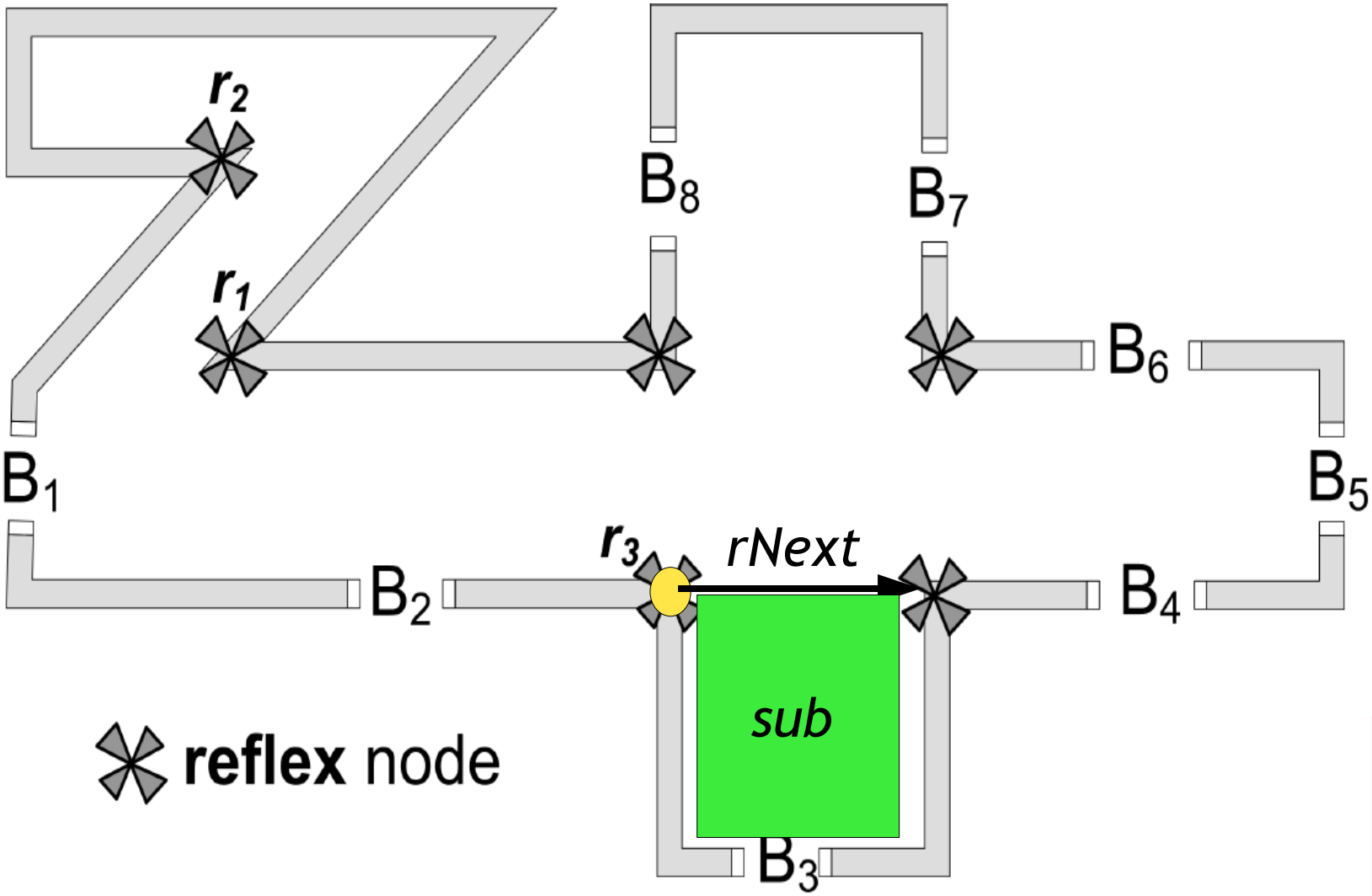

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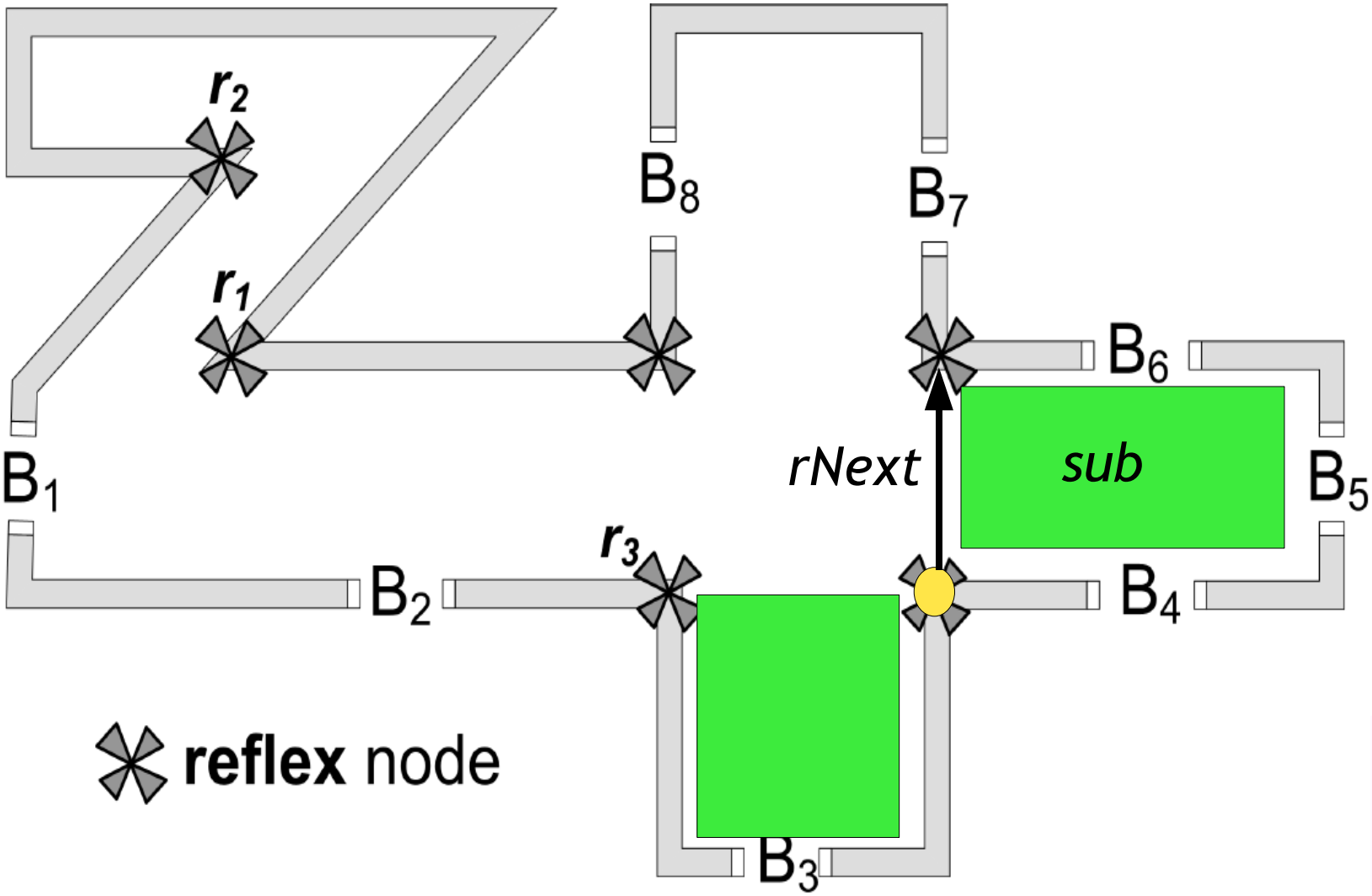

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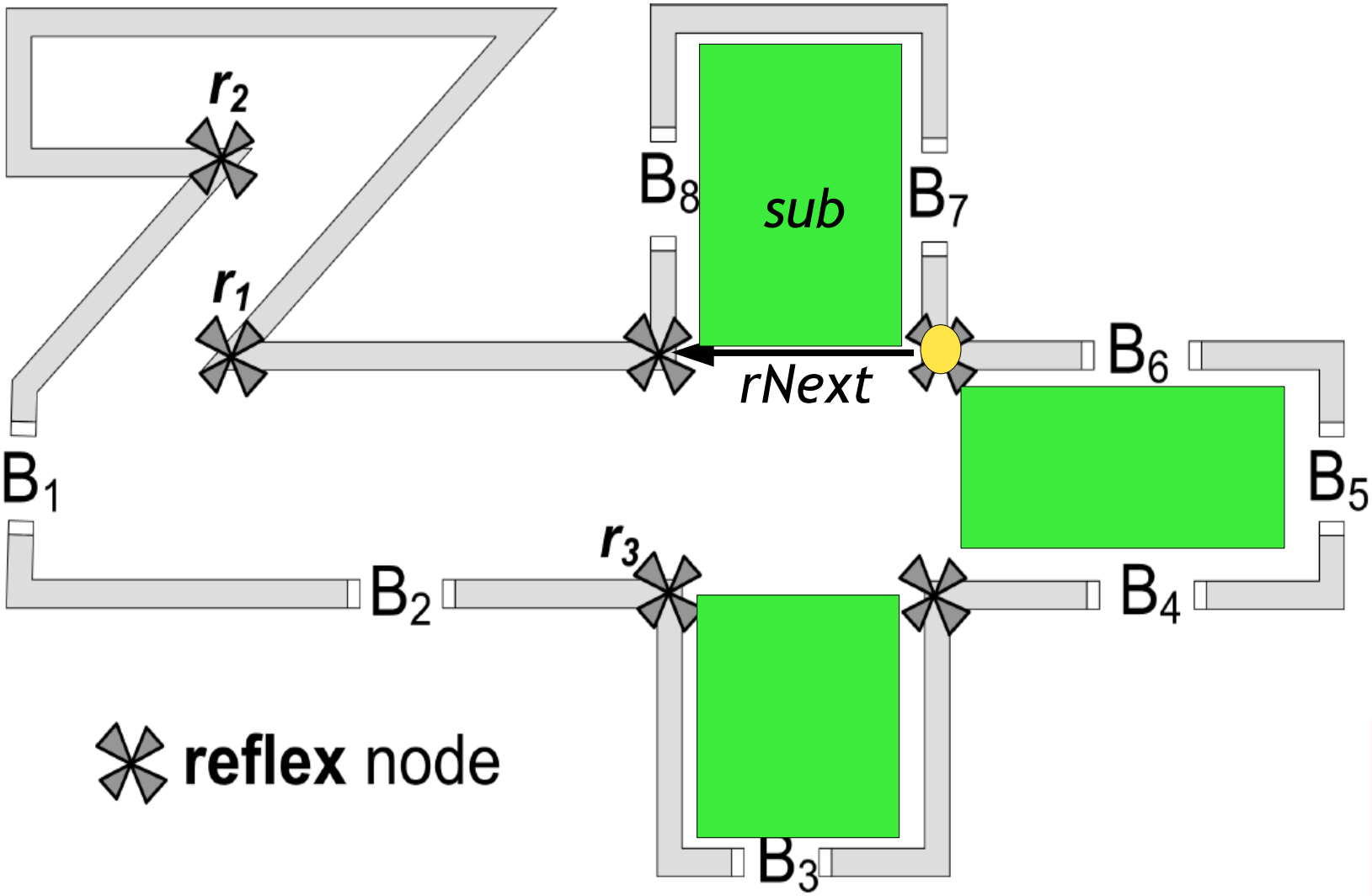

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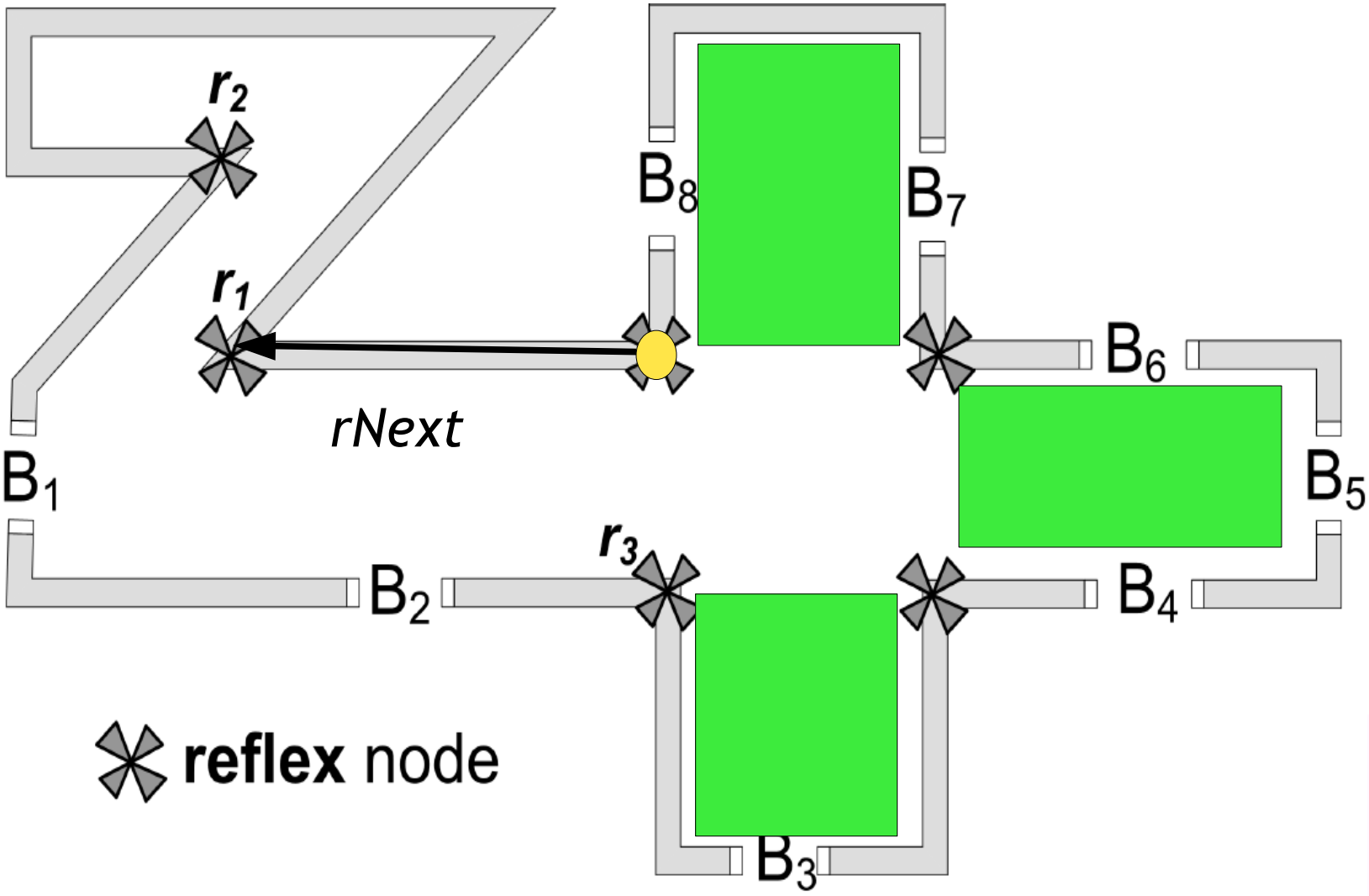

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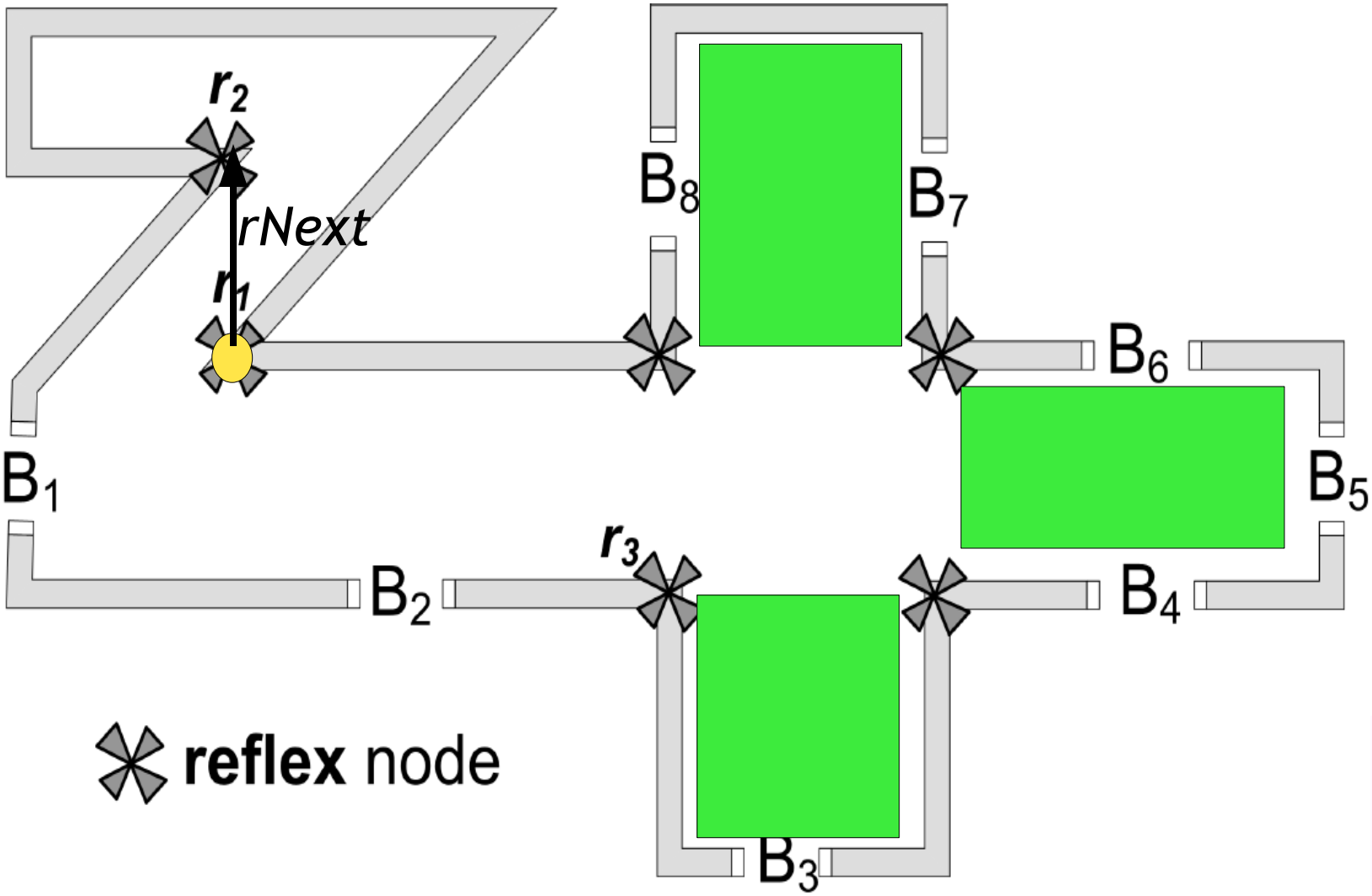

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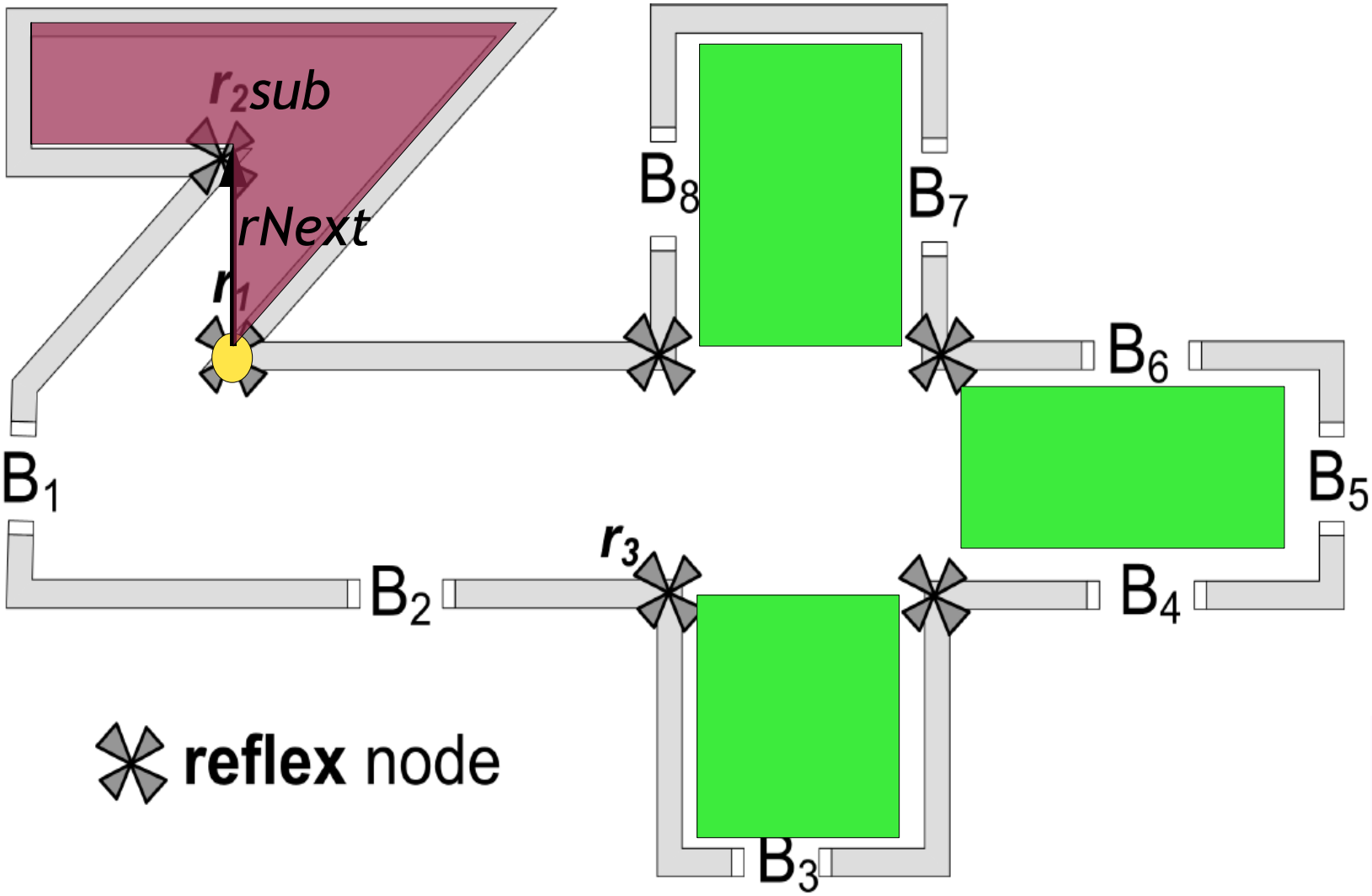

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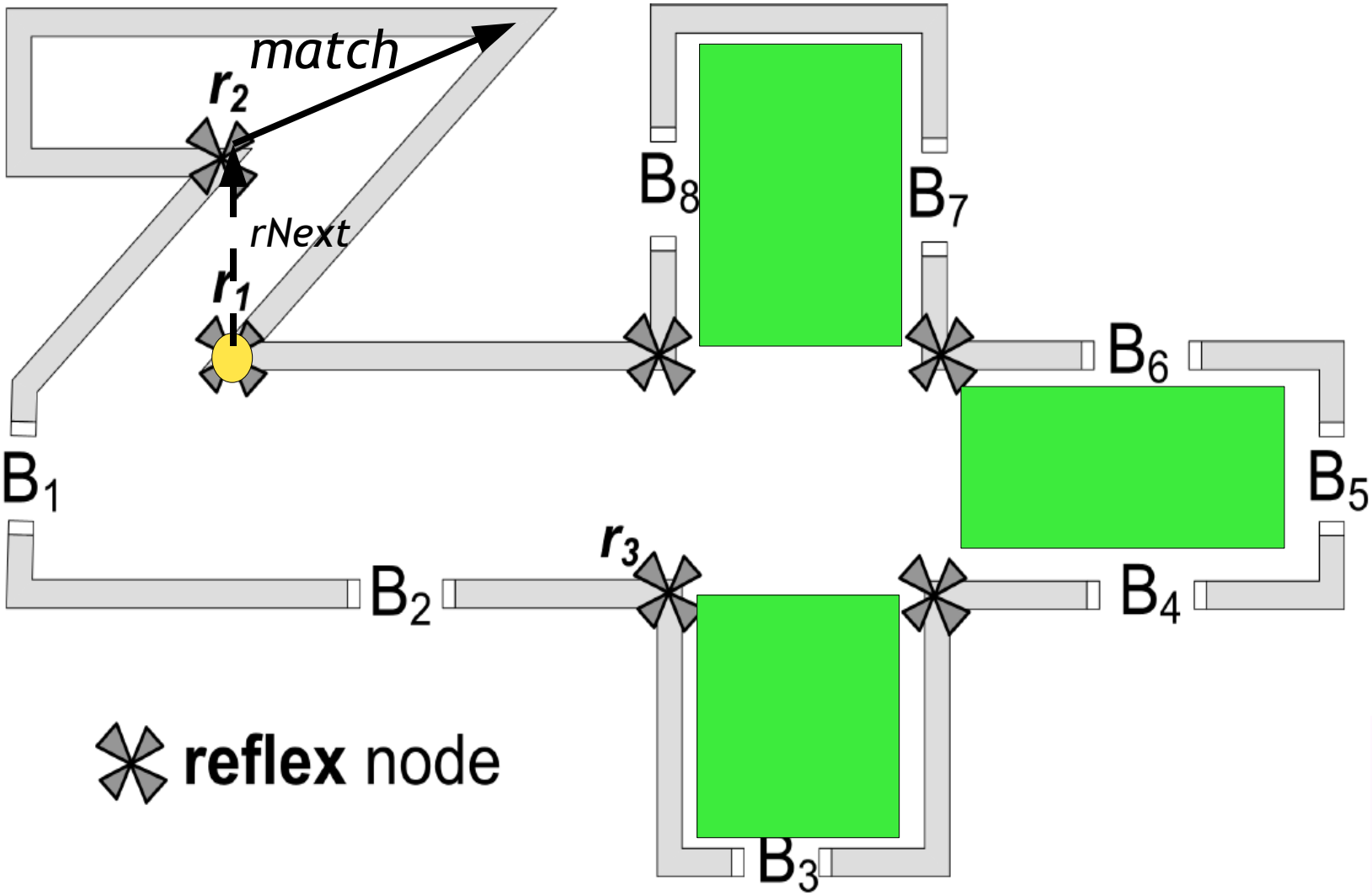

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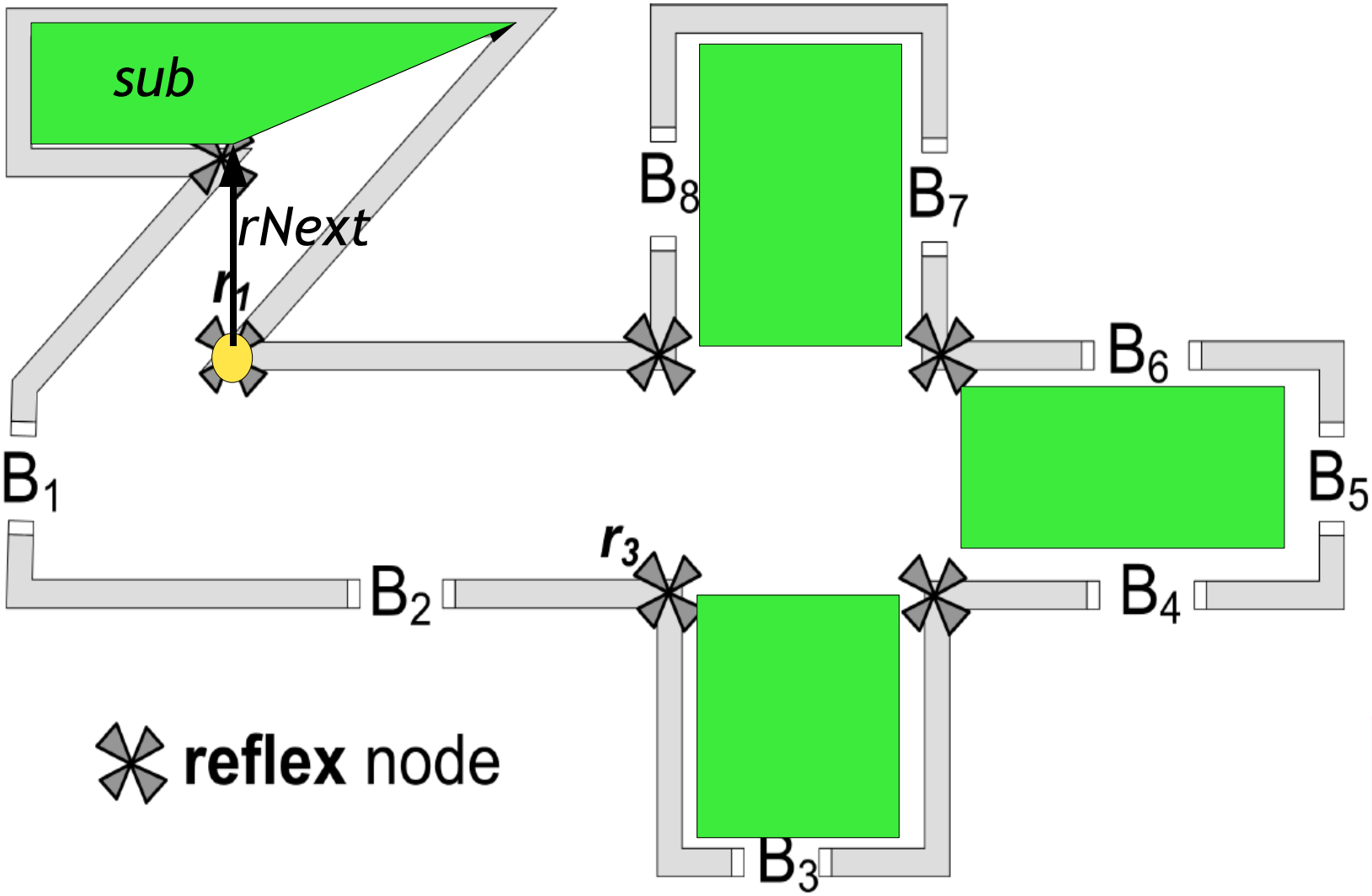

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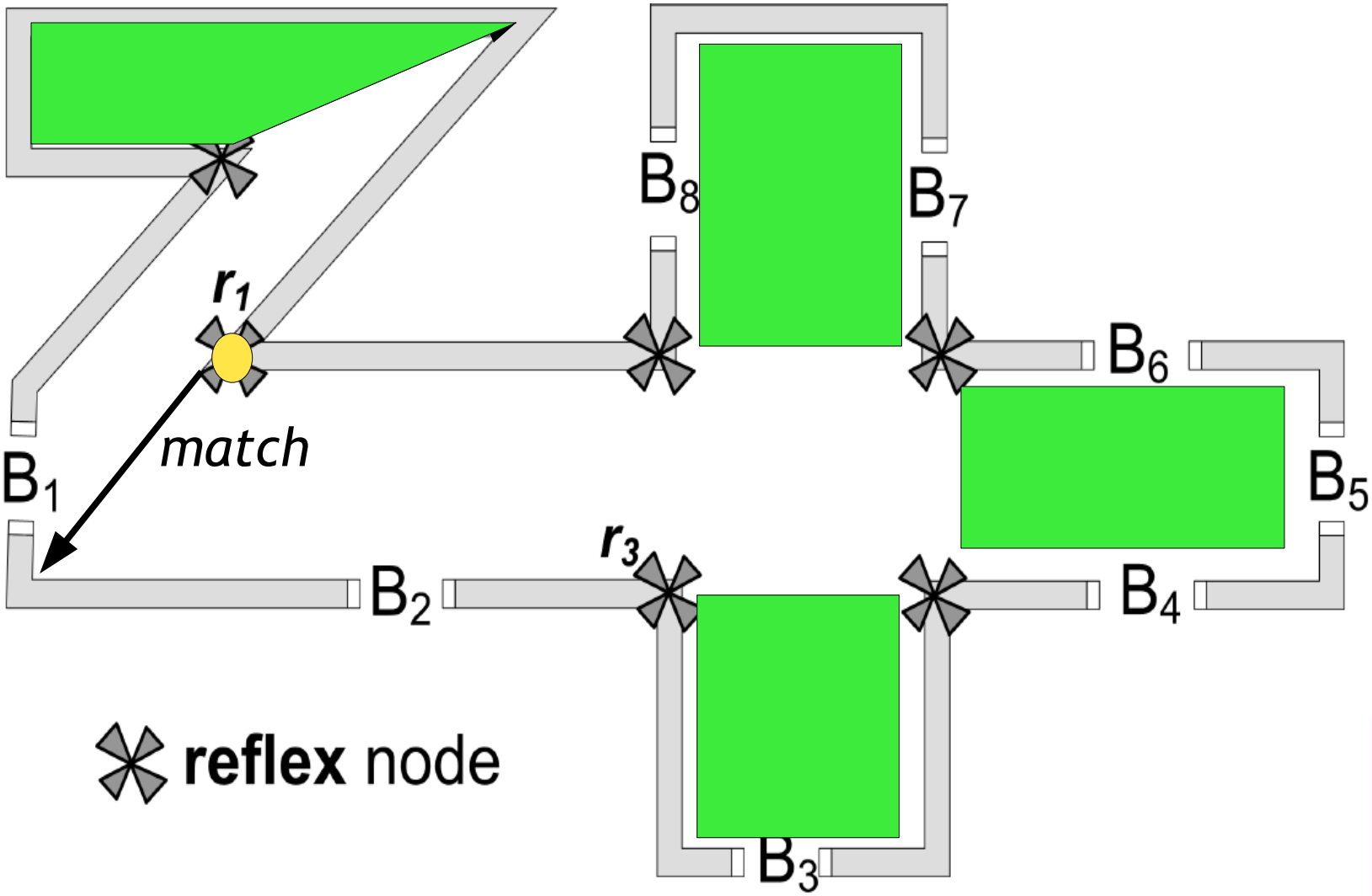

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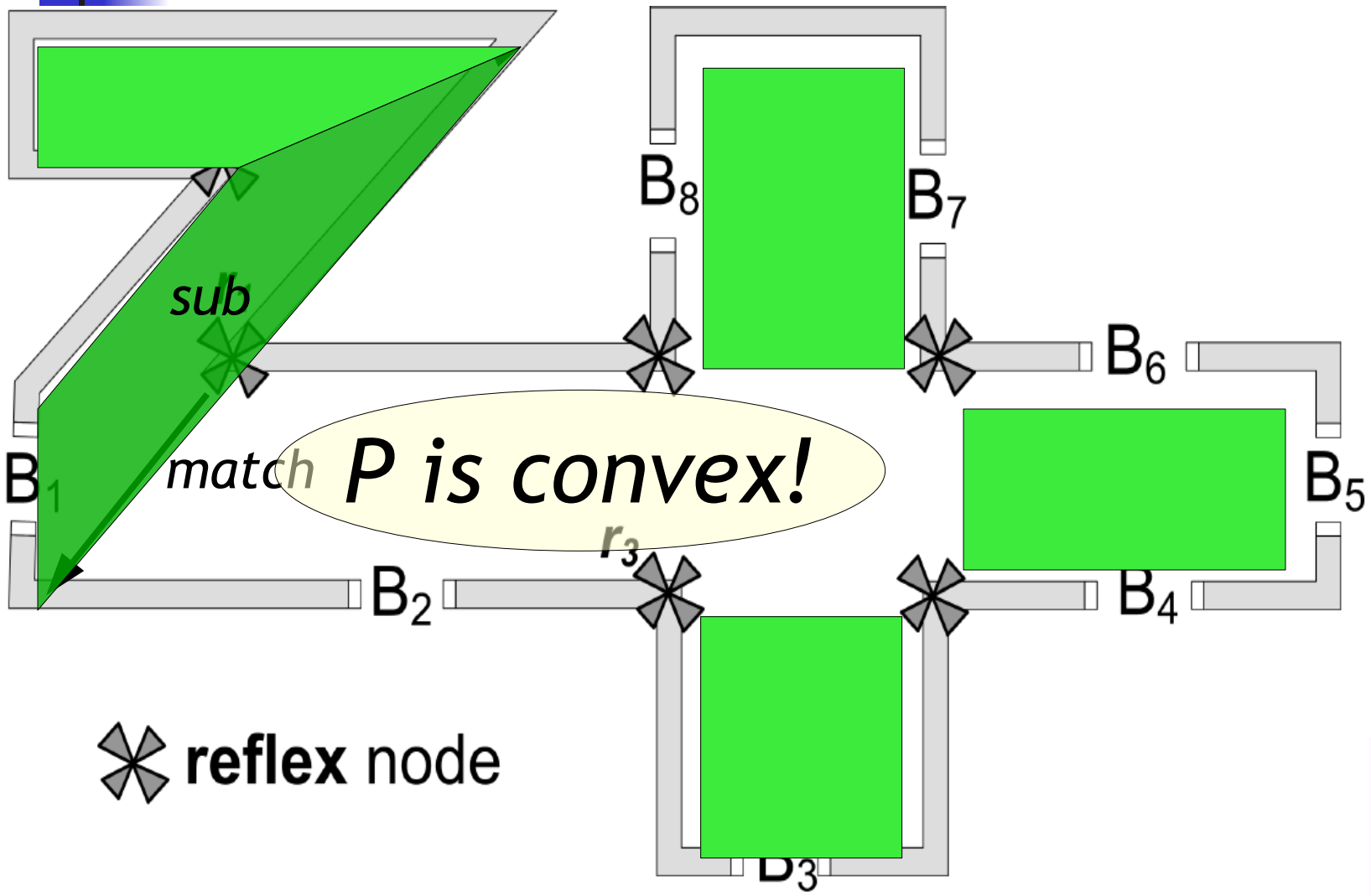
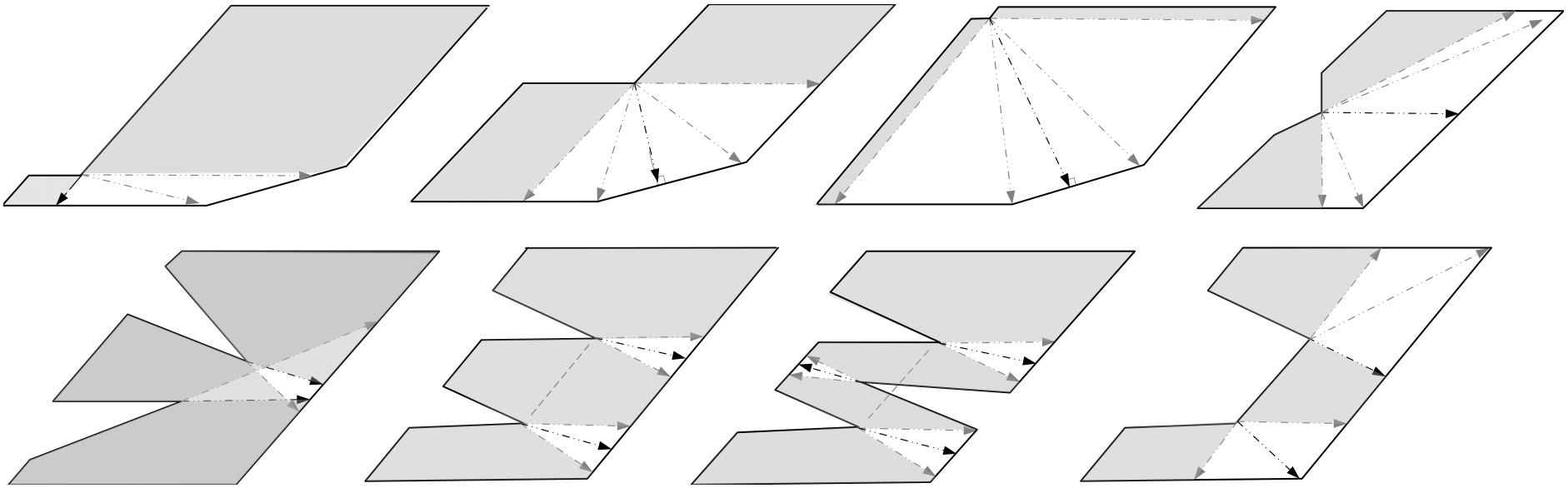


Discussion with Examples

- algorithm not always intuitive:



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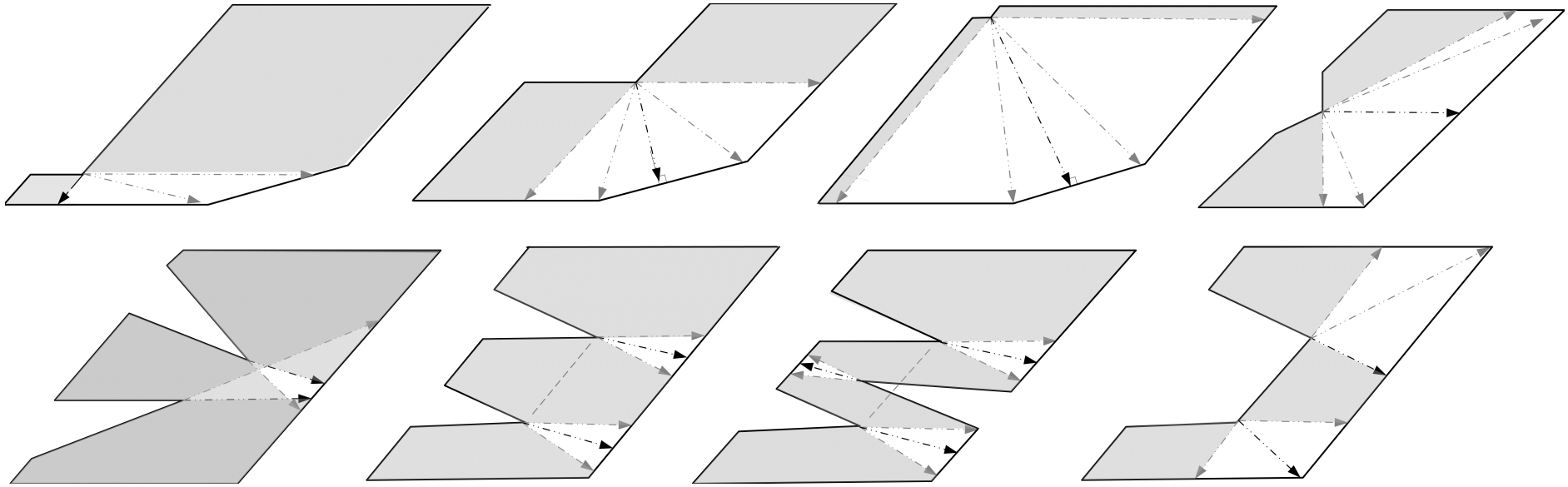
Outlook

- Implementation underway

- What still remains to do:
  - Comprehensive context modelling, involve in wayfinding
  - Query language / conform to standards (OpenLS)
  - Test & evaluation of the model with real data from campus

That's all, for now.

- Thank you for listening!



Questions & Discussion

Involved Research Areas

- Multi-Disciplinary Approach:
  - Computational Geometry (Polygons, ..)
  - Artificial Intelligence
    - ontologies, KR
    - path planning
  - Human Spatial Cognition
    - spatial ontology (landmarks, ..)
  - Geographic Information Science
    - spatial queries, LBS, ..

modelling real world

Movement in Free Space

- topological information alone not sufficient for route descriptions:
  - "*enter* room [through **door A**]"
  - "traverse room until you reach **door D**"
  - "*leave* room [through **D**]"
- how to represent movement?
  - should be natural-looking, but computable
  - straight paths look more plausible
  - smoothness: b-splines

may involve several actions

Path Planning Techniques

- Roadmap Methods
  - Medial Axis
    - Generalized Voronoi Graph
    - max. clearance from obstacles
    - ▽ prune paths to corners
  - Visibility Graph
    - all-pairs ⇨ $O(n^2)$
    - ▽ static, because precomputed
- Cell Decomposition
  - Approximate
    - partial free cells split recursively
    - ▽ results in unbalanced decomposition
  - Exact
    - partitioning of areas
    - ▽ many ways to do so

Hybrid Location Modelling

- Geometric
  - shape, orientation ⇨ determine visibility
  - quantitative data from positioning system ↳ determine symbolic location
  - display on map
- Symbolic
  - the way humans specify locations: "*Where* are you?" - "Room 1.02 on first floor"

both needed!

Symbolic Model

- spatial regions ⟺ polygons
- topological relations among regions
  - distinct:
    - "contained-in" implies hierarchy
    - "connected-to" implies graph

classical RCC-8/9-intersection relations..

- ..not sufficient because
  - adjacent not in the sense of navigation
  - multiplicity not captured
- ..overkill: only distinct regions, no overlap!

Classification of Method

Recall:

- Roadmap Methods
  - Medial Axis
  - Visibility Graph
- Cell Decomposition
  - Approximate
  - Exact
    - Convex decomposition