The Moon and Sixpence

Ansgar Fehnker

The Moon and Sixpence

- 2001 to 2004 PostDoc ECE/SCS
  - Hybrid System verification and CEGAR
- 2004 to 2011 NICTA Sydney
  - MC for static analysis: **Goanna**
  - MC for Manet and Mesh
- 2011 to now University of the South Pacific
  - 12 Member countries
  - 14 campuses, main campus in Suva, Fiji.

The Moon and Sixpence

- Goanna
  - Static Analysis Tool for C/C++
  - Combines model checking, path queries on parse tree and interval solving
  - Interprocedural (Function Summaries)
  - False positive elimination (SAT solving)
  - For any C/C++ code
  - Participant in SATE (NIST)
  - More on **Goanna: redlizards.com**

TOPOLOGY BASED MOBILITY MODELS FOR WIRELESS SYSTEMS

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Mobility

- Wireless networks, Mesh, MANET, are designed to deal with mobile nodes.
- Protocols have to deal with nodes that join, disappear, or change neighbors.
- Incorporating mobility into models has been a challenge.

Mobility

- Formal state based models often
  - consider static topologies.
  - considered set topology changes.
  - ignored topology (considered an unspecified or non-deterministic topology)

- Aim: Creation of Mobility Models
  - to be used for Model Checking
  - independent of the protocol (re-use)
  - simple (not adding too much complexity)

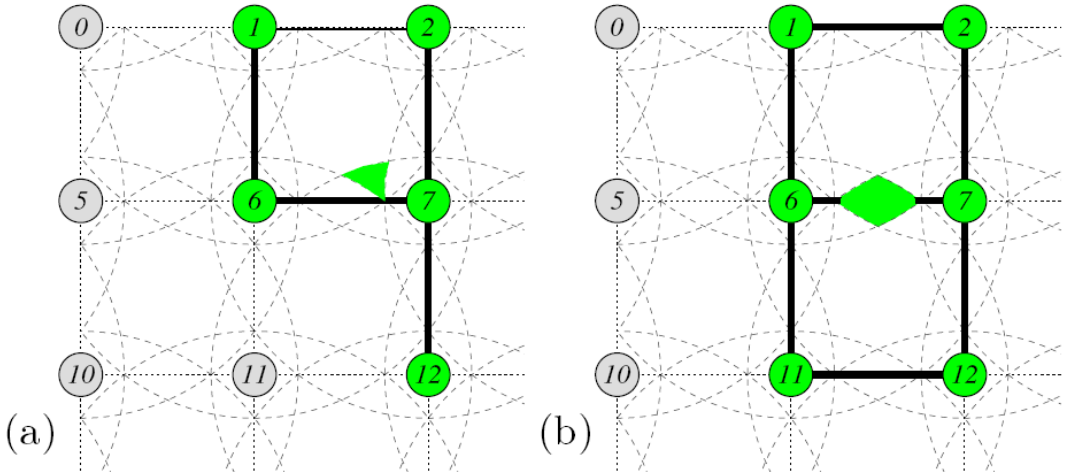
Topology Based Mobility

- Idea
  - Model mobility as changes between topologies.
  - Transitions will be probabilistic.
  - Abstract from location, speed, or size of the node.

- Rationale
  - The topology is what the protocol usually sees.
  - Compatible with untimed, or timed automaton models for protocols.

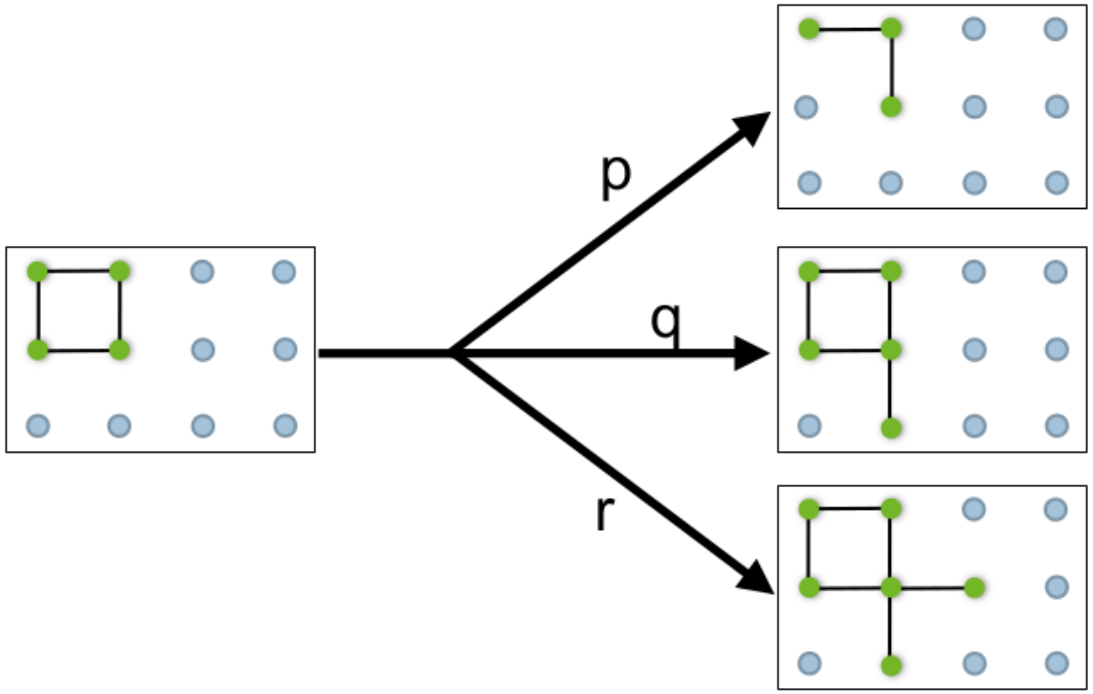
Topology Based Mobility

- The mobile node is characterized by its neighbors (nodes within range)
- Space will be partitioned into regions with the same topology.



Topology Based Mobility

- Mobility is expressed as probability of moving from one region/topology to the next.



- What are the probabilities?

Two step approach

1. Mobility simulation
   - Using a “traditional” simulator to estimate the transition probabilities between topologies.
2. Probabilistic mobility model
   - Instantiate a probabilistic automaton model of mobility with obtained probabilities.
   - Combine this model with a probabilistic automaton model of a protocol.
   - Use a (statistical) model checker to analyse the impact of mobility on performance of the protocol.

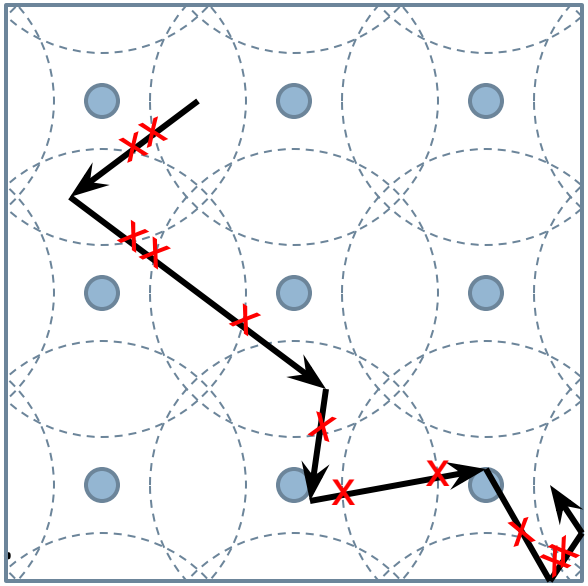
Simulator

Implemented in C++.

- Computes a series of waypoints; each successive pair defines a line segment.
  - RWP: Next waypoint selected uniformly from area.
  - RW: Next waypoint is old plus value from 2-D normal distribution. Reflect at boundary.

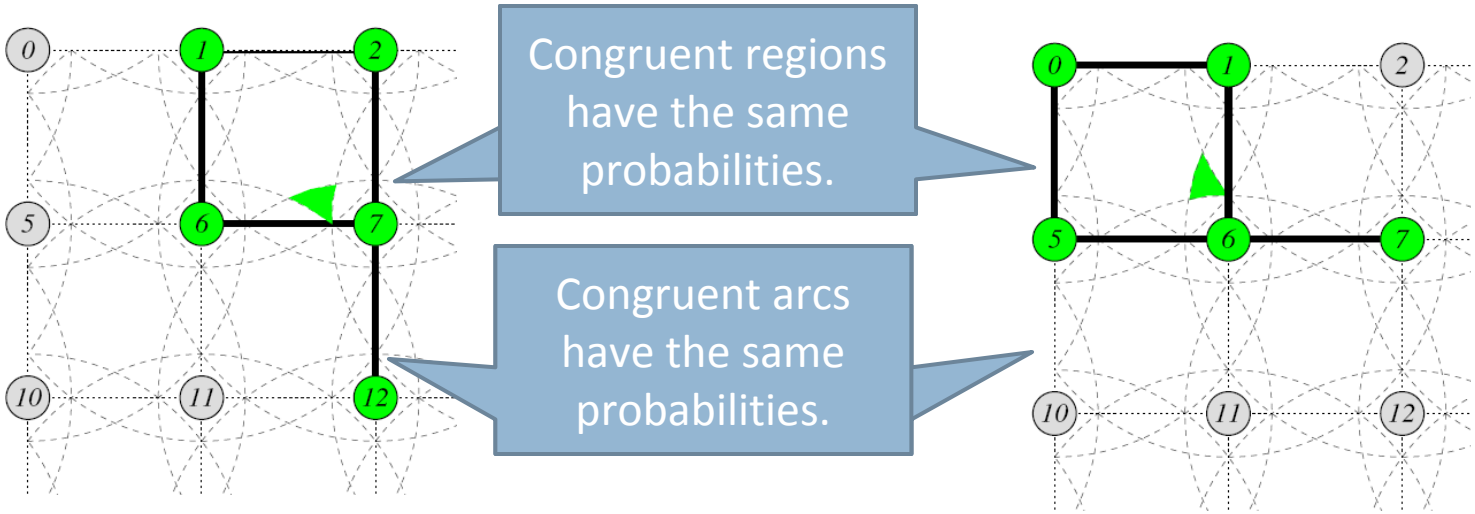
100000 waypoints

- Computes intersection of line segment with transmission ranges.
- Each intersection corresponds to a transition.
- Count transitions. Estimate probabilities.



Simulation Results

- Some observations for the random walk model
  - The transition probabilities are independent of σ and the grid size;
  - The number of transitions per waypoint path grows linear with the range;
  - The transition probabilities of congruent transitions are the same;
  - The probabilities depend only locally on the set of nodes within range.



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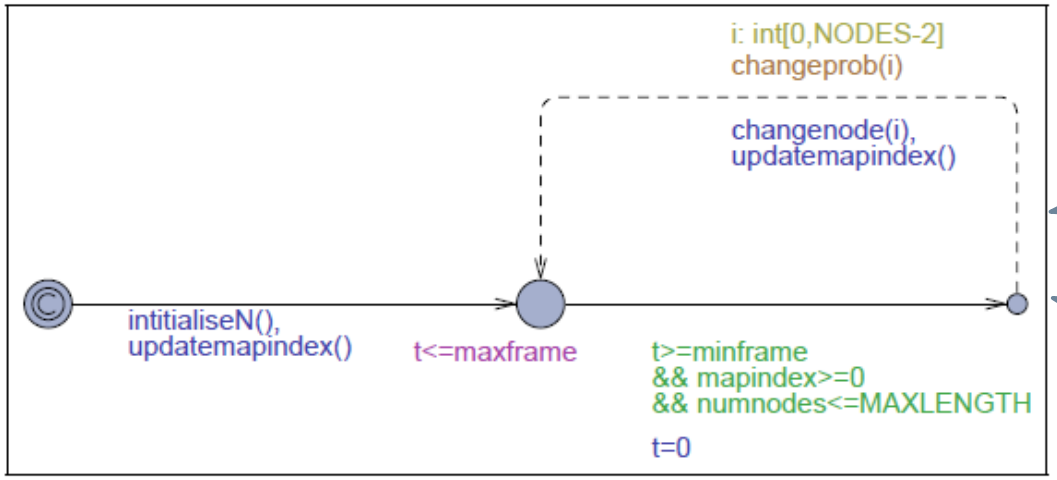
  - The probabilities depend only locally on the set of nodes within range.
- One observation for the random waypoint model
  - Neither of the above observation holds

Model Checking Results

- We use statistical Uppaal.
  - Properties checked with 0.95 confidence.
  - The topology is modeled as a connectivity matrix.
  - Changes in topology are changes to the matrix.
  - Probabilities are obtained from a lookup table (obtained from simulator, as discussed)



"One" probabilistic transition to change the topology

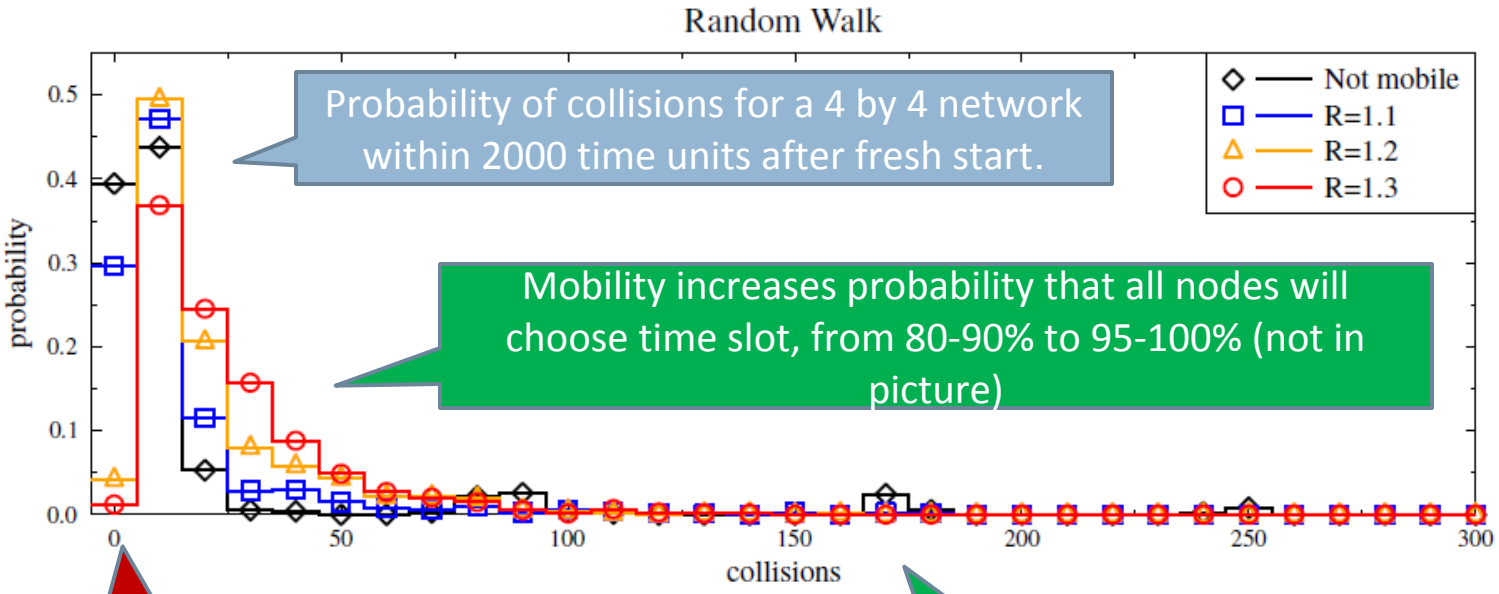
Changes topology once in a given timeframe

Model Checking Results

- We combine probabilistic mobility model with existing protocol models to demonstrate the approach.
- AODV
  - An on-demand routing protocol
  - A routing request is flooding the network, a routing reply to initiator will report the route.
- LMAC
  - A time synchronization (time division) protocol.
  - All neighboring nodes and their neighbors, need to select different slot in a time frame. If not, collisions will occur.
  - A new node listens to the neighbors and selects a time slot different from them and their neighbors.

Model Checking Results

- LMAC



Probability of collisions for a 4 by 4 network within 2000 time units after fresh start.

Mobility increases probability that all nodes will choose time slot, from 80-90% to 95-100% (not in picture)

Mobility decreases probability that no or few collisions will occur.

Mobility decreases probability that perpetual collisions will occur.

Results for RWP are similar

Summary

- Developed a topology based model for mobility.
- Demonstrated how this model can be instantiated with probabilities obtained from a simulator.
  - Random way point model and random walk model in a grid.
  - Other models that give transition probabilities could be used as well.
- Demonstrated how the instantiated mobility model can be combined with existing probabilistic protocol models.
  - Note: AODV and LMAC are not the primary interest of this work. They were application examples.

Thanks

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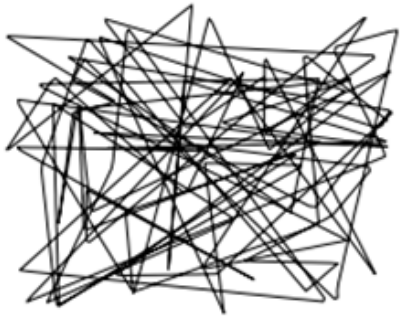
Mobility Models

- Realistic Mobility Models
  - Replay traces obtained from real world
  - Application specific scenarios, with limited scope.
- Synthetic Models
  - Generate traces from mathematical model of motion
  - Usually based on a physical model of a moving node
  - More than a dozen different models
    - Random waypoint models
    - Random walk models
    - Manhattan models
    - Gravity mobility models
    - ….

Common Models

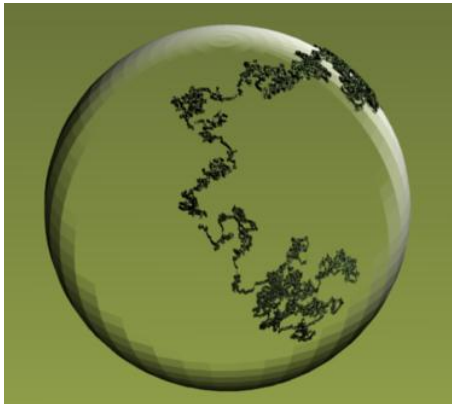
- Random Waypoint Model (RWP)
  - Select the next waypoint uniformly from abounded,
  - Choose a speed with certain probability.
  - Choose a waiting time with a certain probability.
  - May include additional probabilistic choices.



- Random Walk Models (RW)
  - Select a direction uniformly.
  - Choose a speed, and distance with certain probability.
  - Choose a waiting time with a certain probability.
  - Plus some rules what to do if the a boundary is hit.
  - May include additional probabilistic choices.

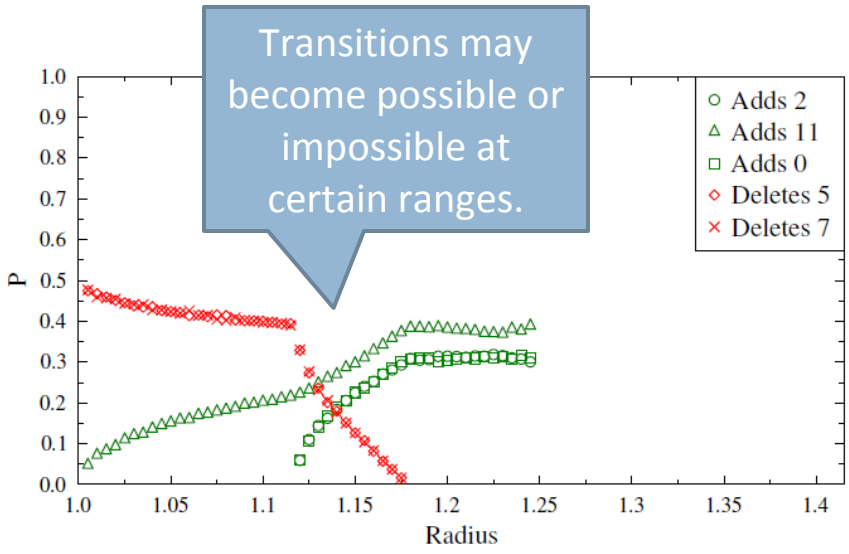
Synthetic Models

- A note on synthetic models
  - Synthetic models do not, by definition, replay reality
  - Some might be more realistic than others
  - The purpose is to have a model
    - with well understood probabilistic behavior
    - that is compatible with chosen analysis method
    - with identifiable factors of motion
    - that has parameters that can be changed
    - and those changes have predictable influence on the behavior
  - It will be hard to find mobile nodes in reality, that move like a node in a synthetic model.

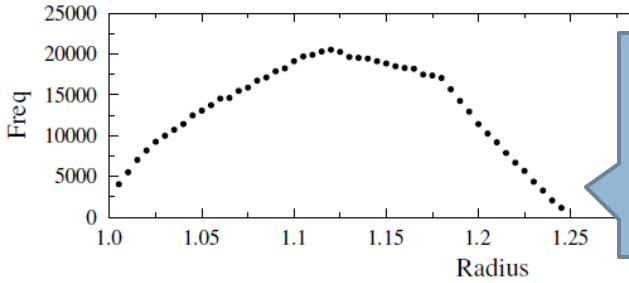


Simulation Results

- Some observations for the random walk model



Transitions may become possible or impossible at certain ranges.



The entire set may become possible or impossible at certain ranges.

Adding either has the same probability

Deleting either has the same probability

Simulation Results

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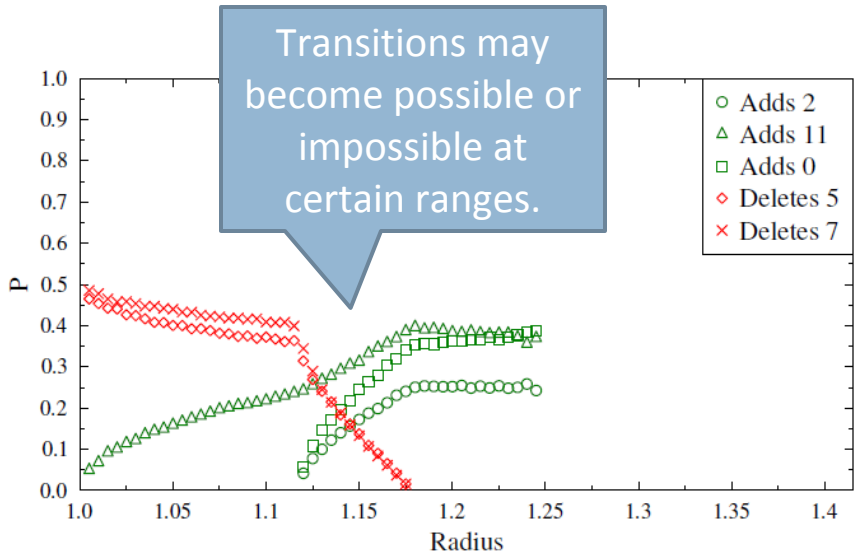
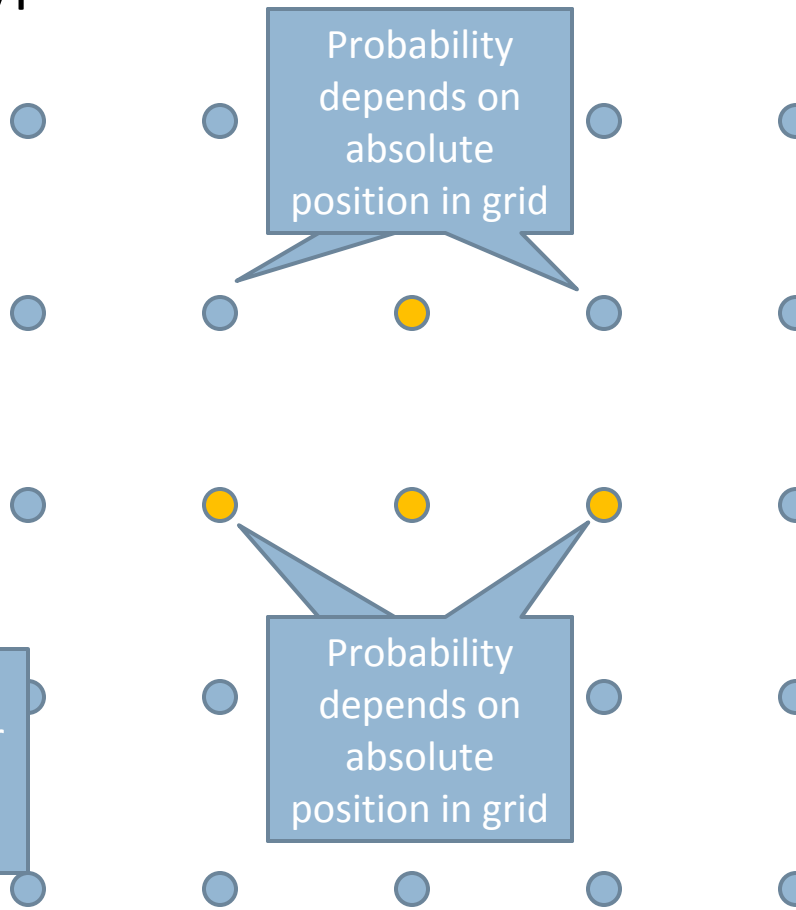
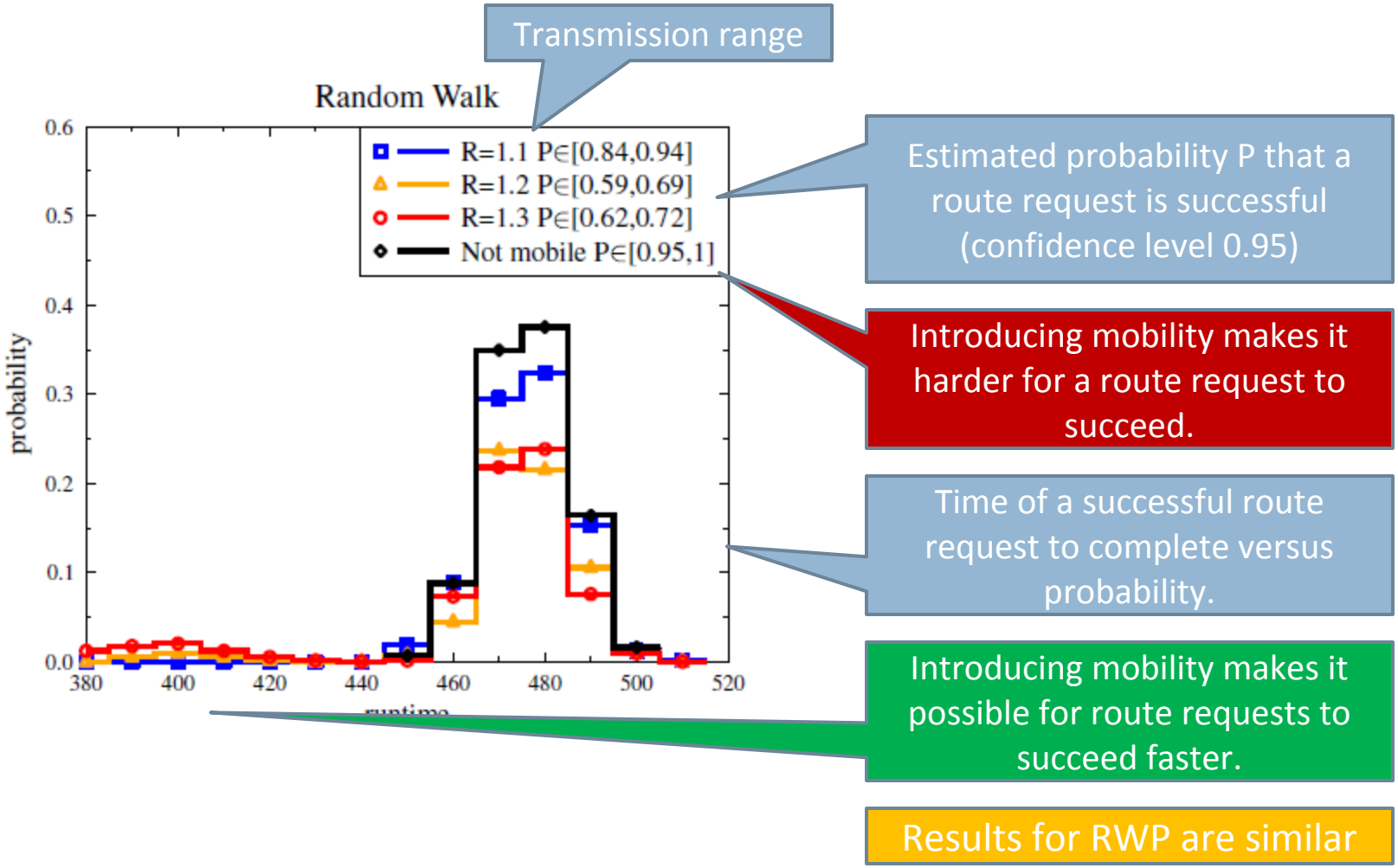




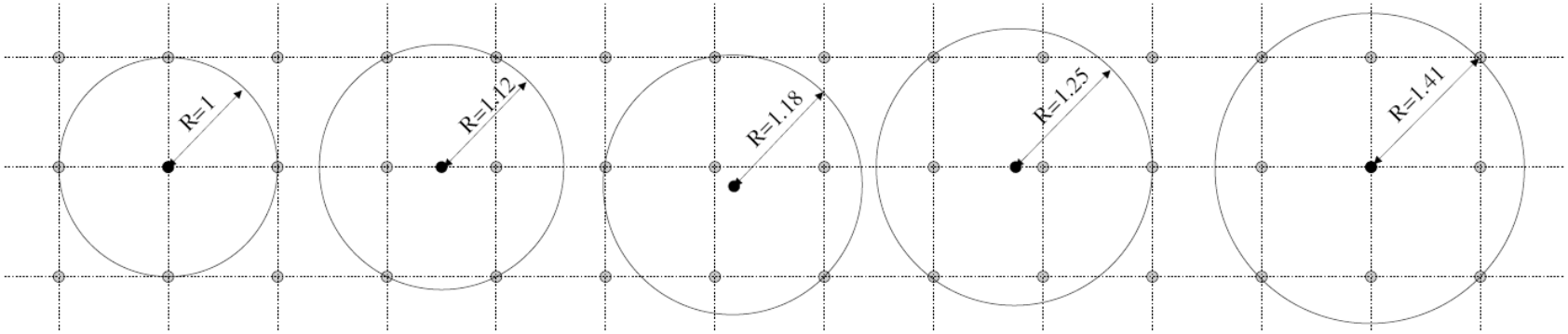
Model Checking Results

- AODV Results



Range and Topology

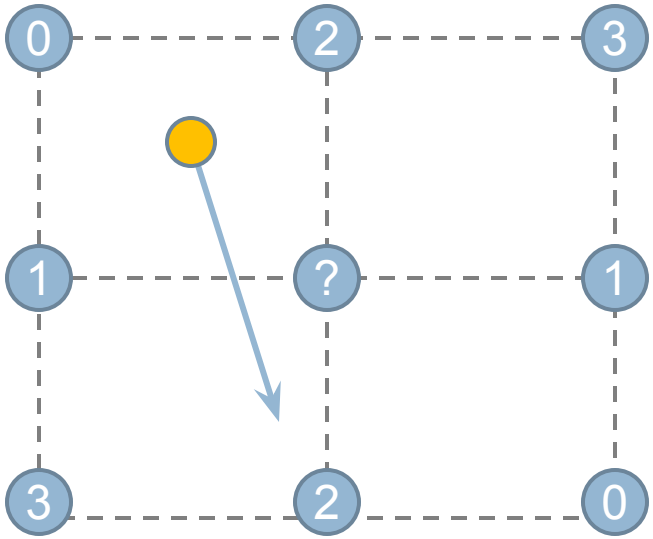
- Different transmission ranges, allow for different topologies.



- Possible topologies change at range $1, \frac{1}{2}\sqrt{5}, \frac{5}{6}\sqrt{2}, 1.25, \sqrt{2},$

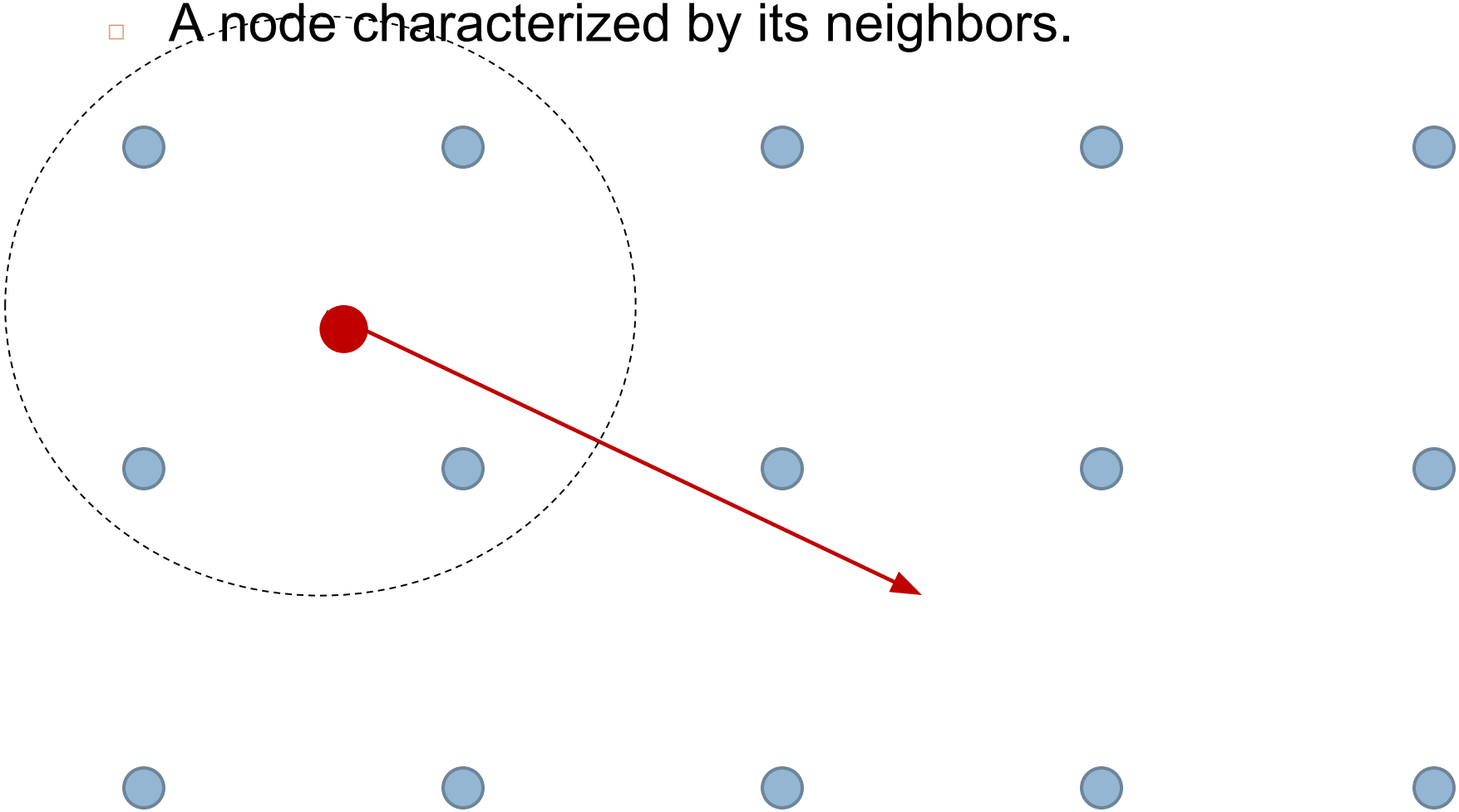
Perpetual collision in LMAC

- Numbers denote a chosen time slot
- The central node receives only noise
- Mobile node can detect, and resolve collision.



Topology Based Mobility

- A node characterized by its neighbors.



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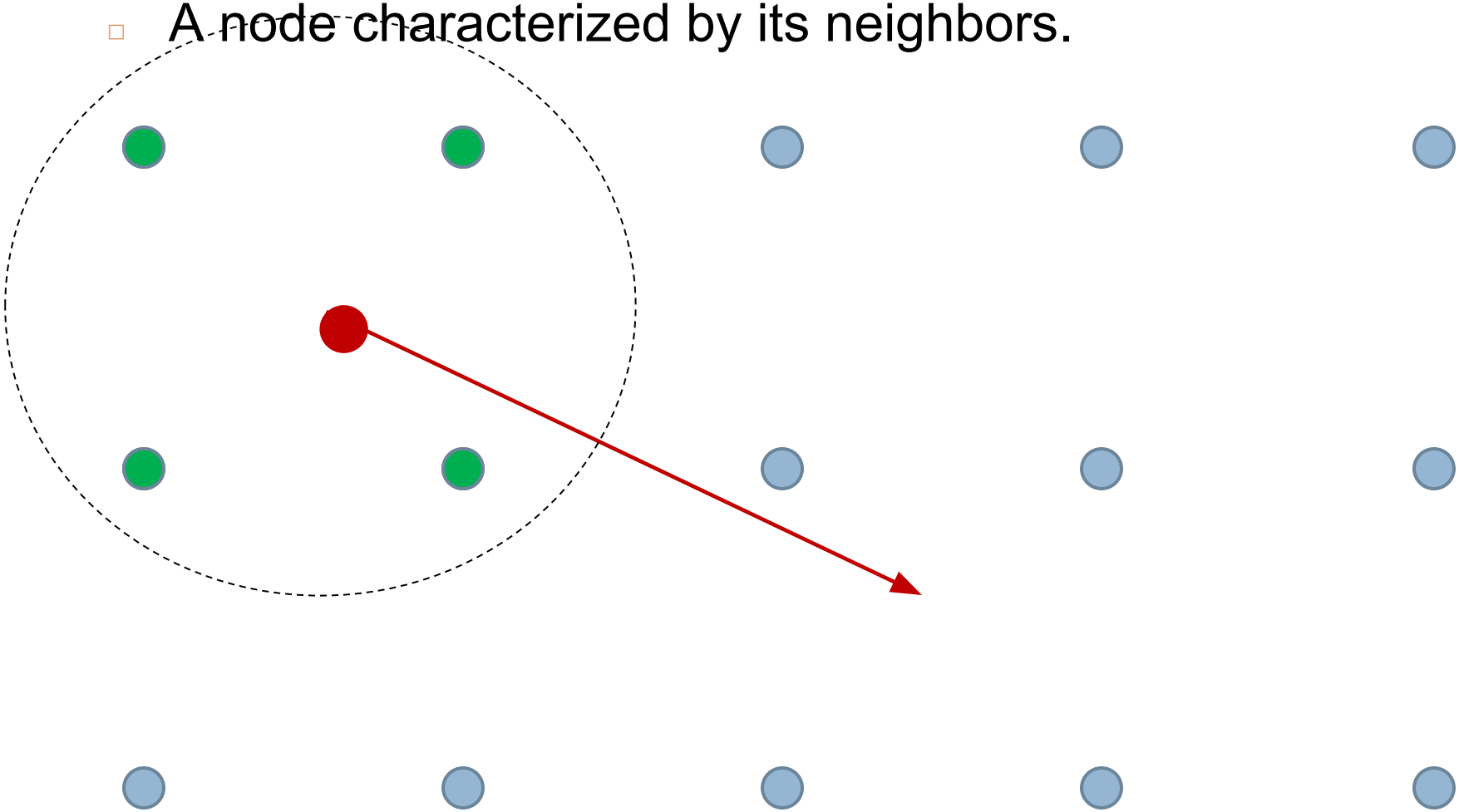

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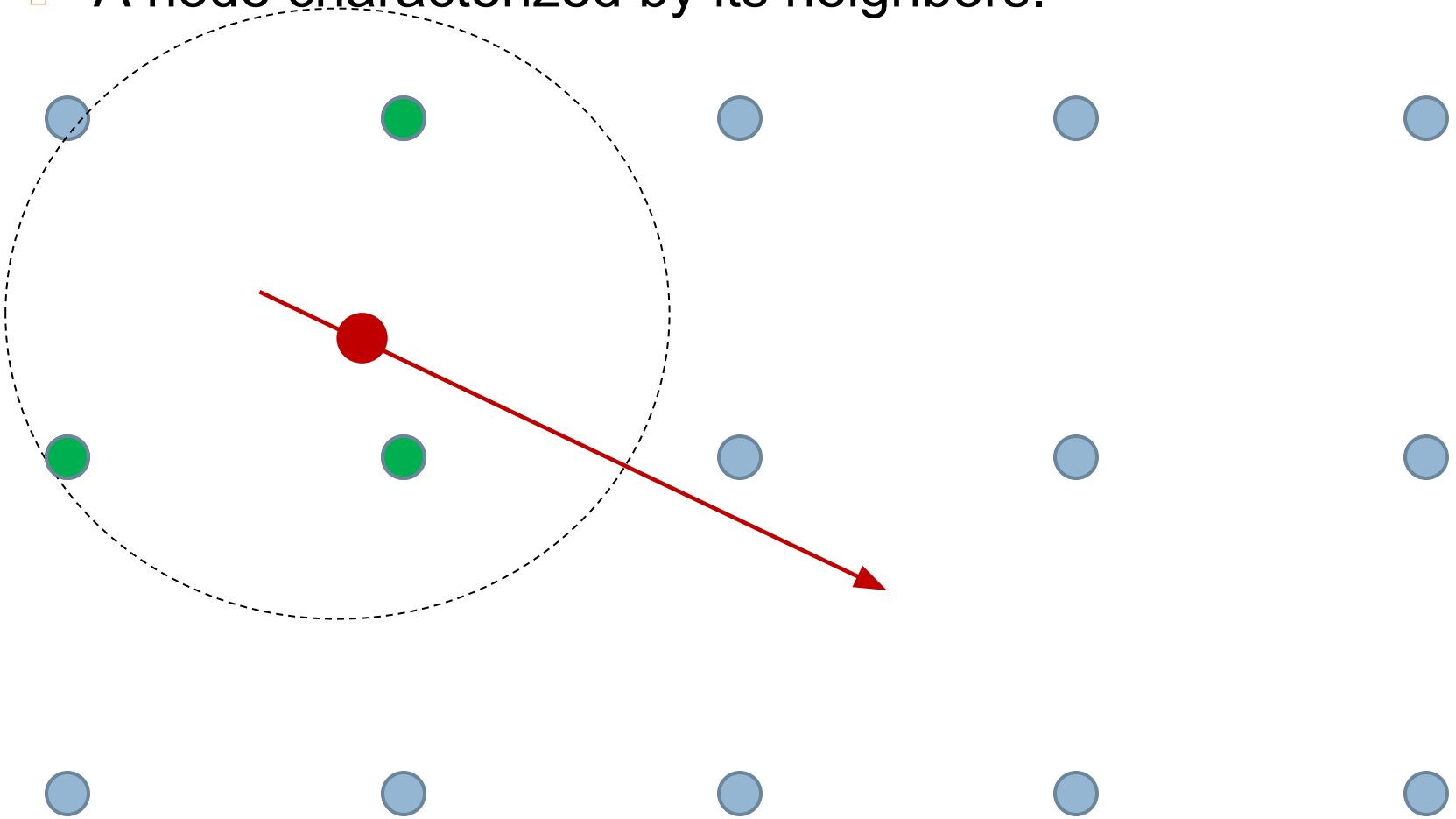

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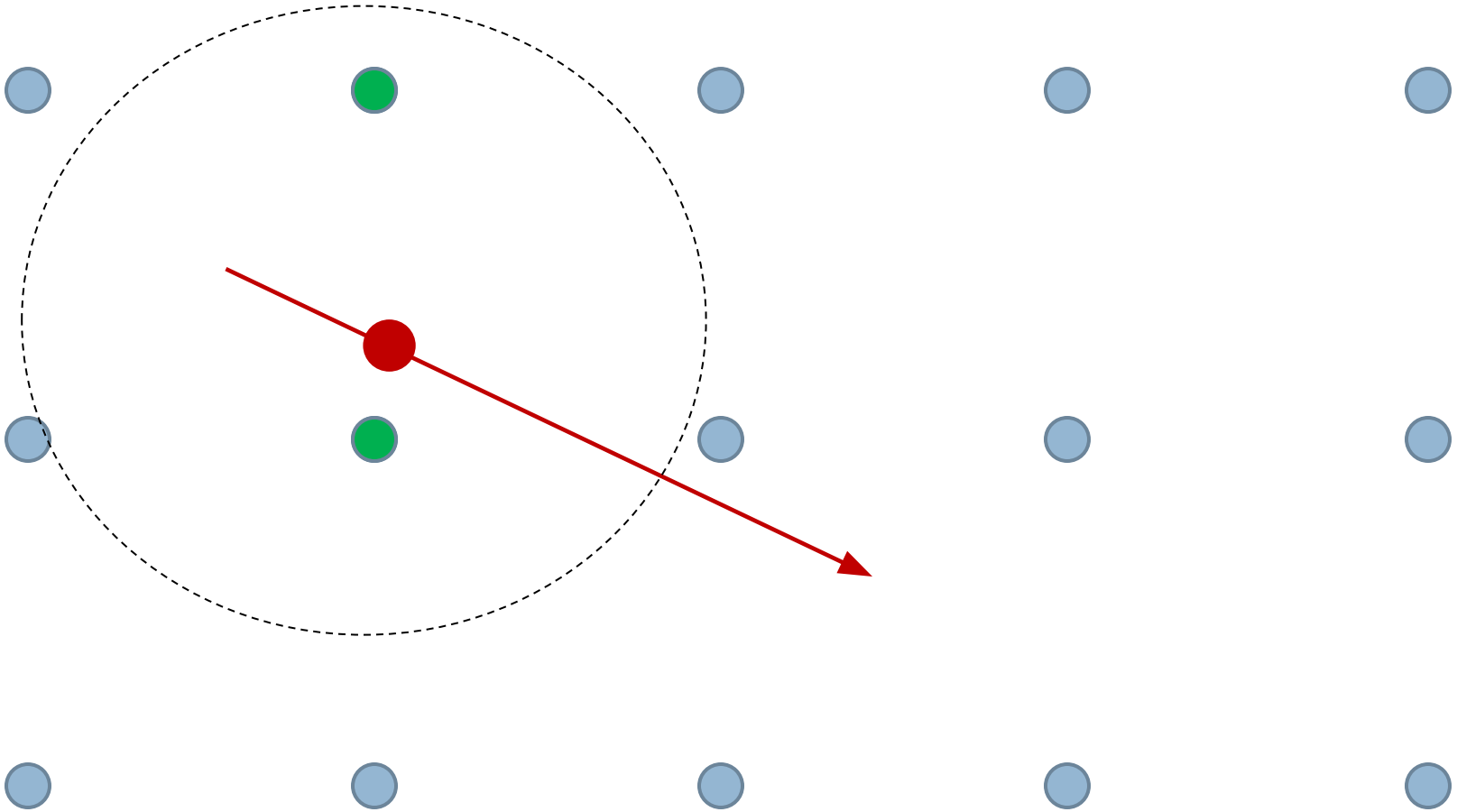

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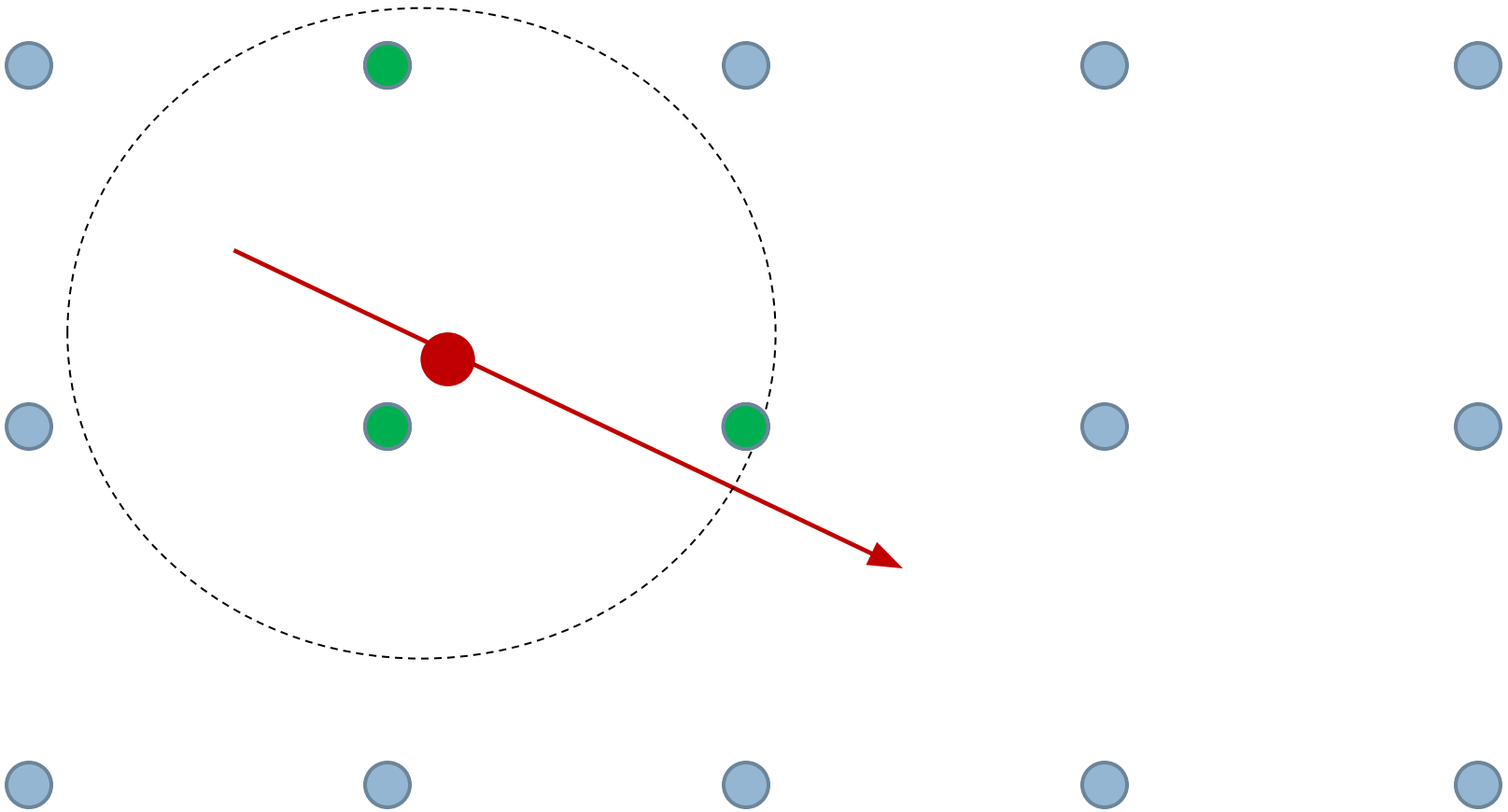

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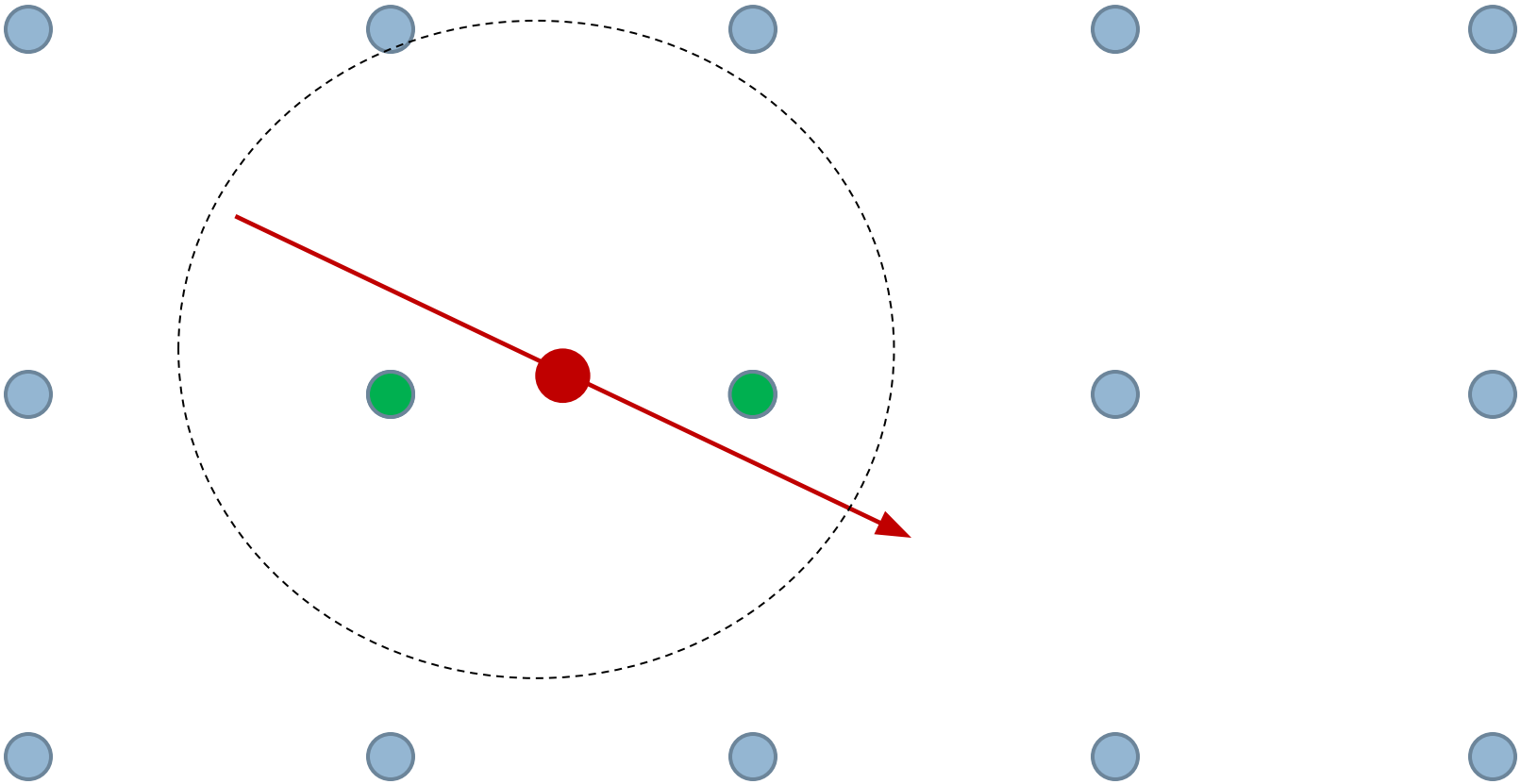

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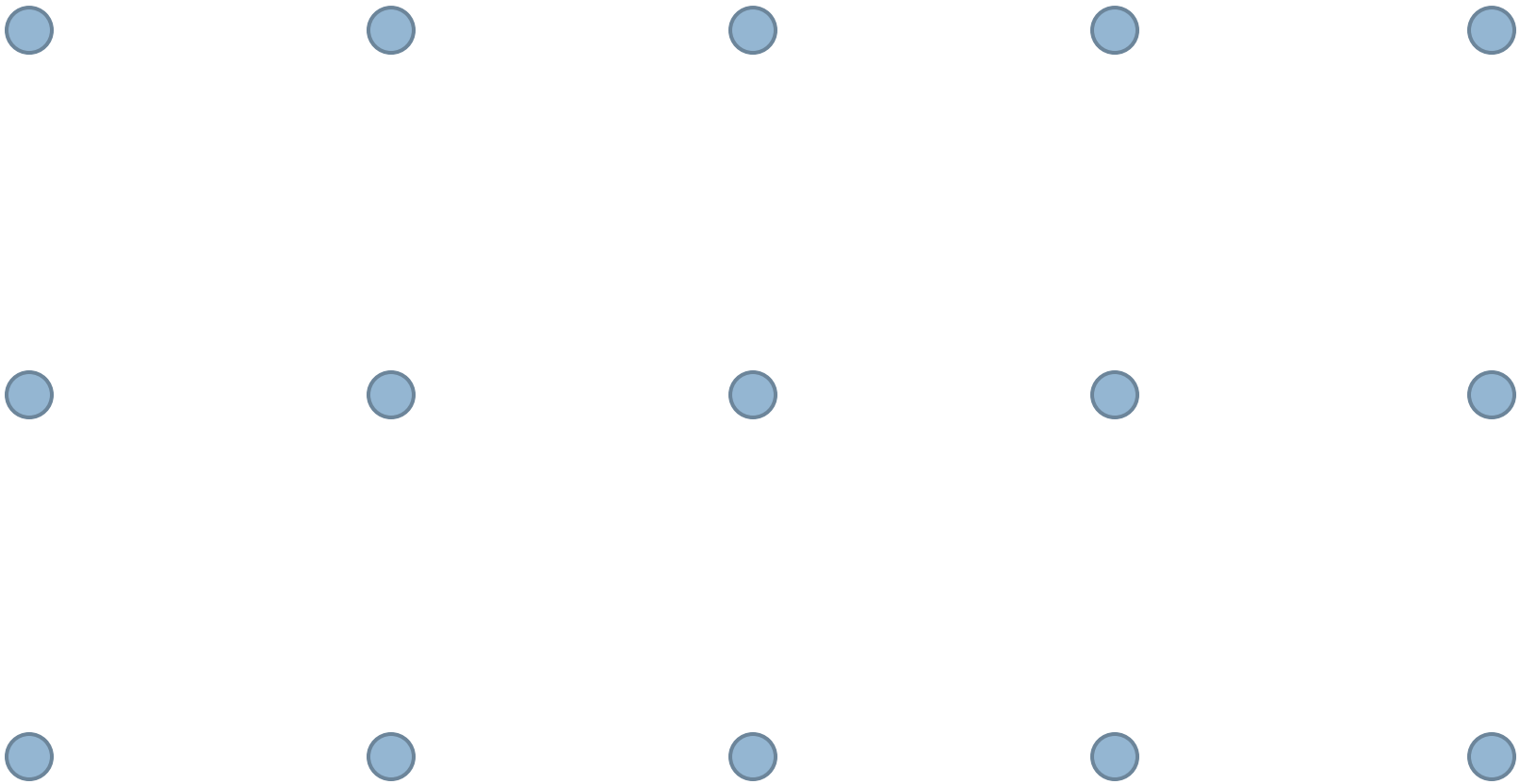

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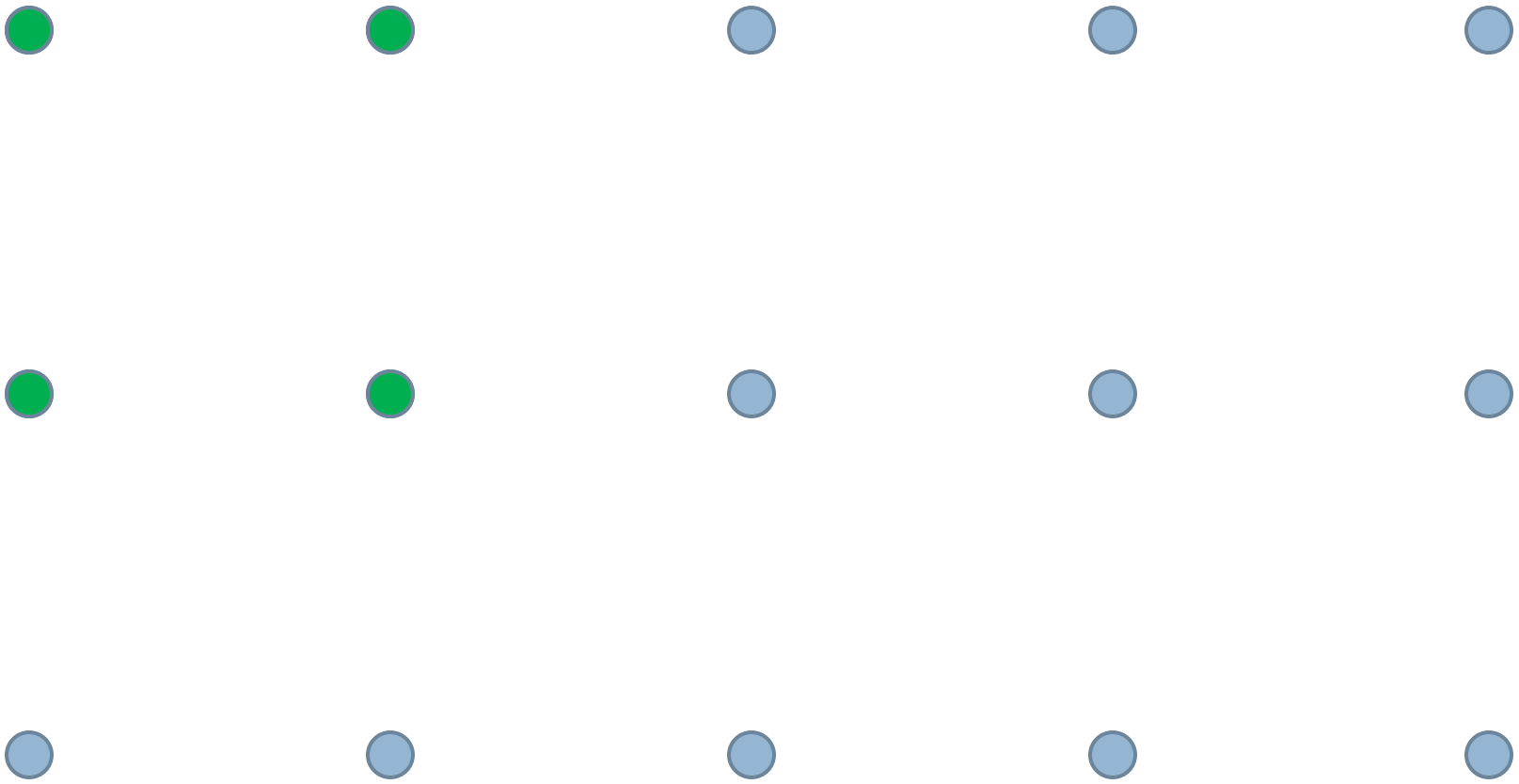

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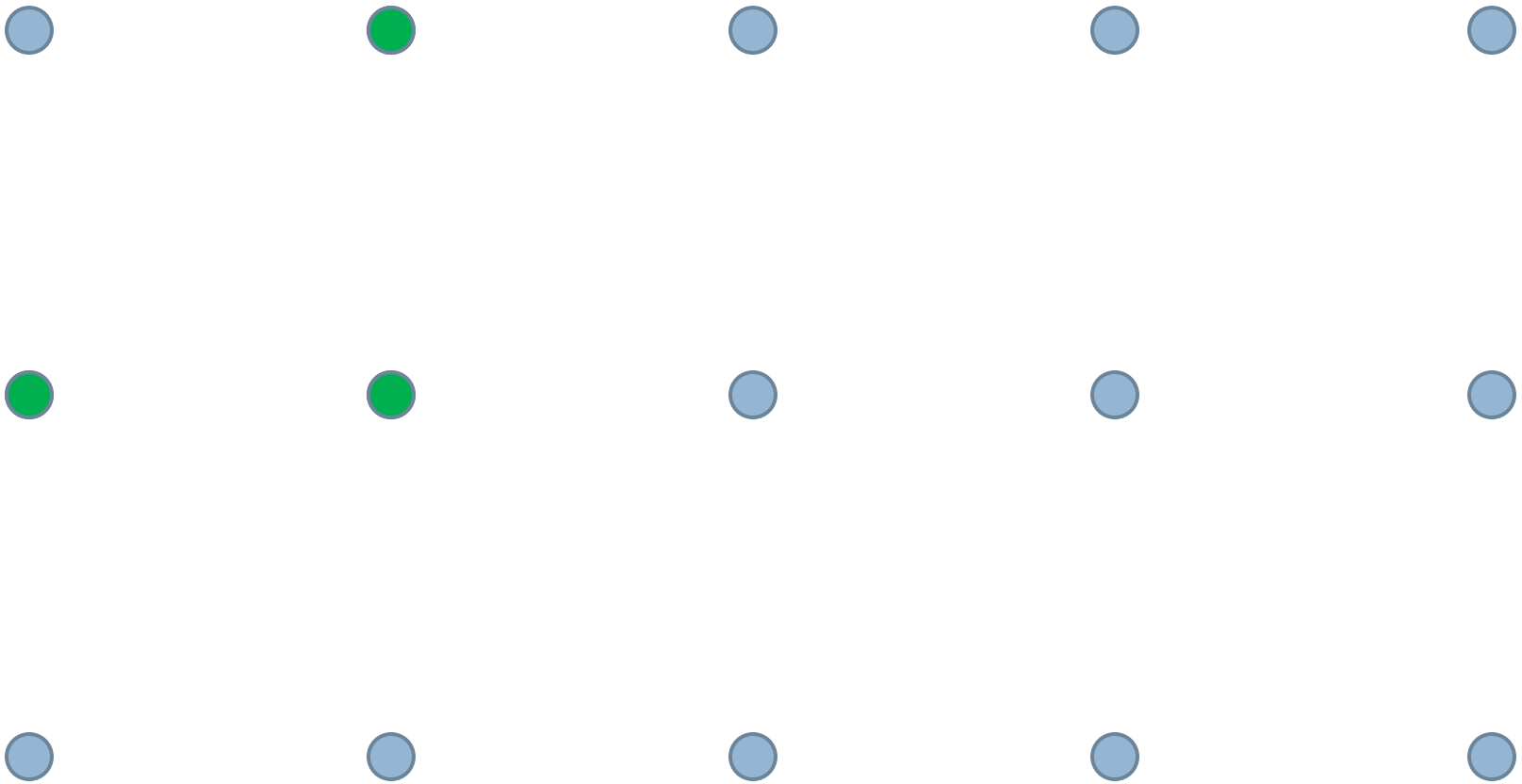

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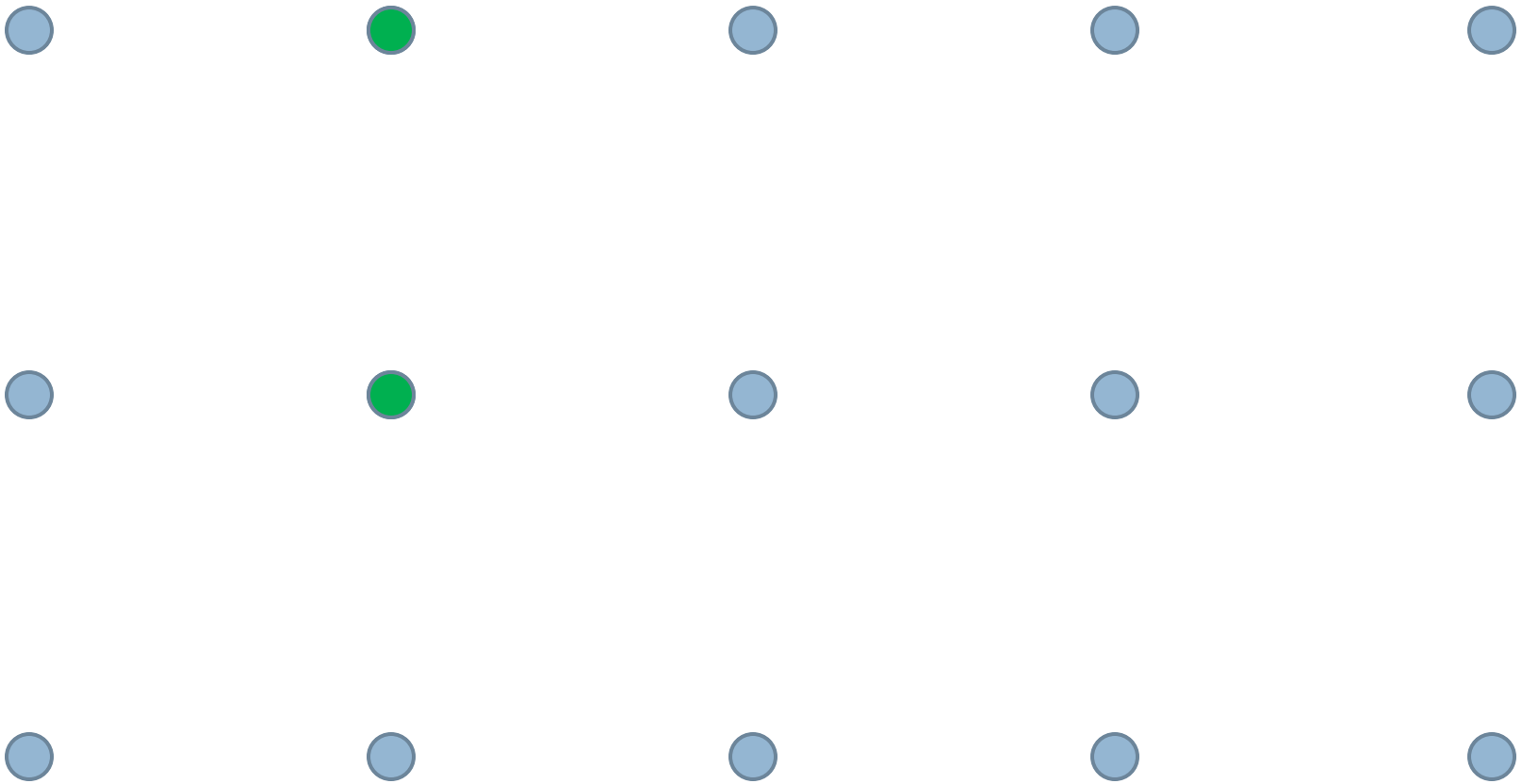

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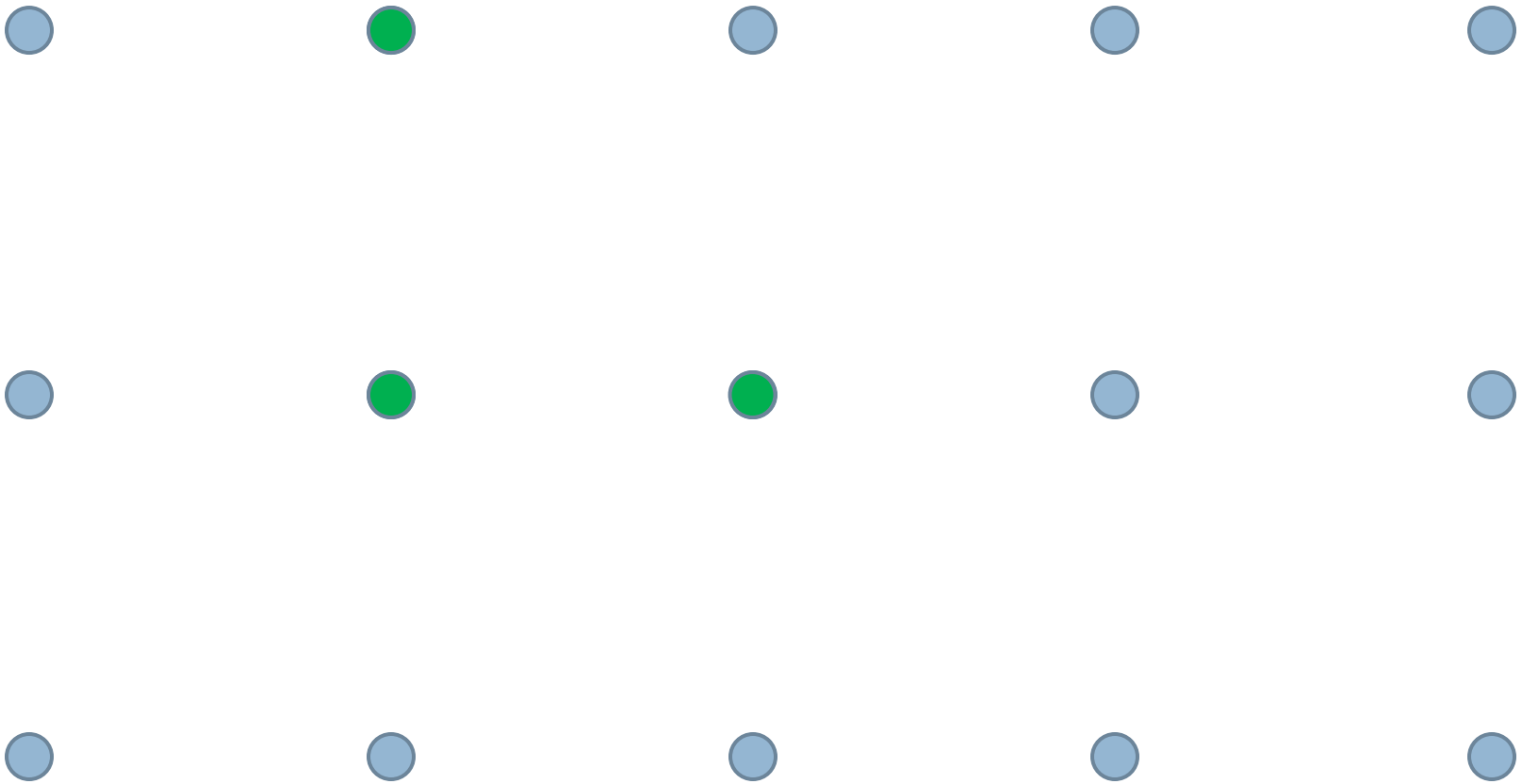

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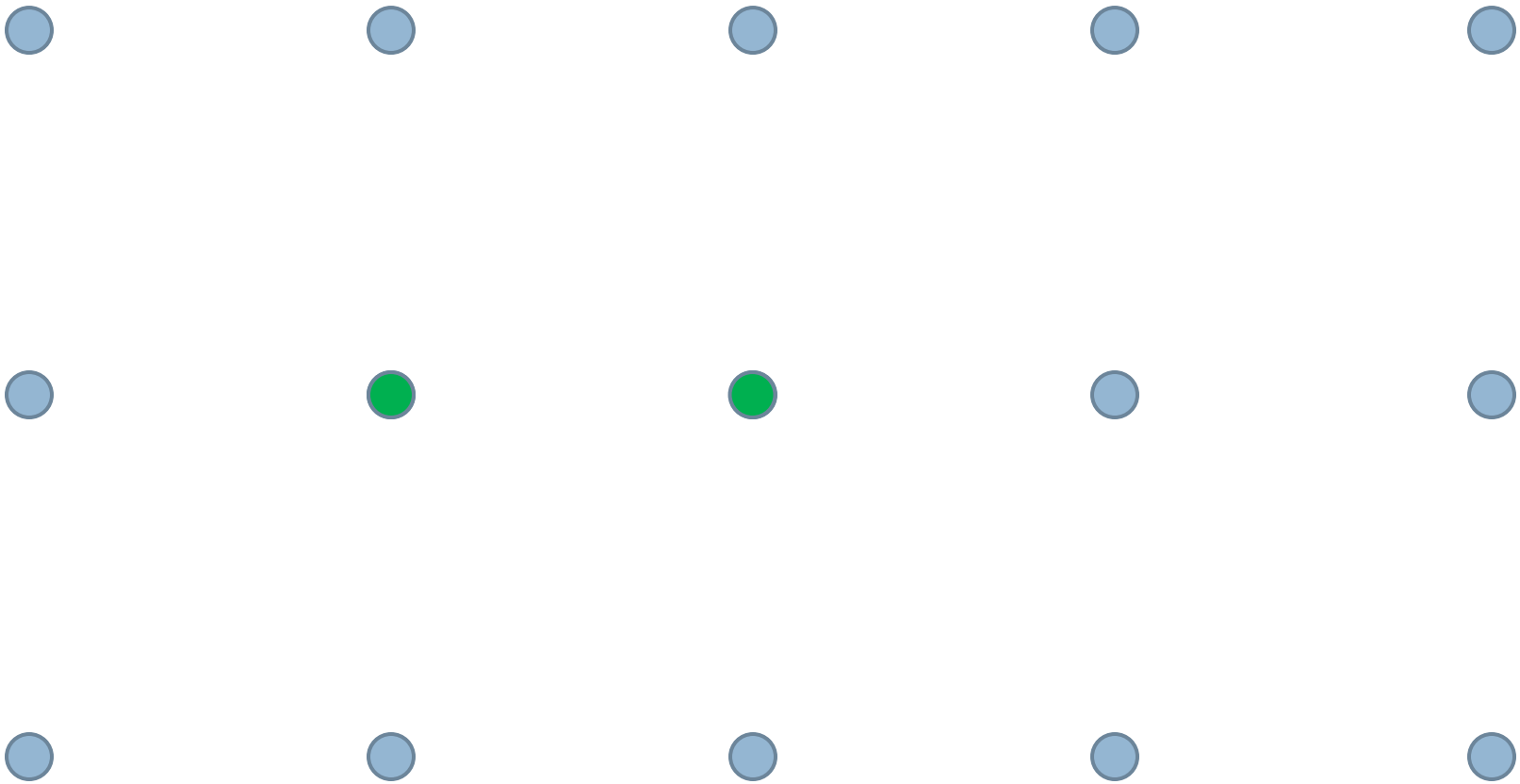

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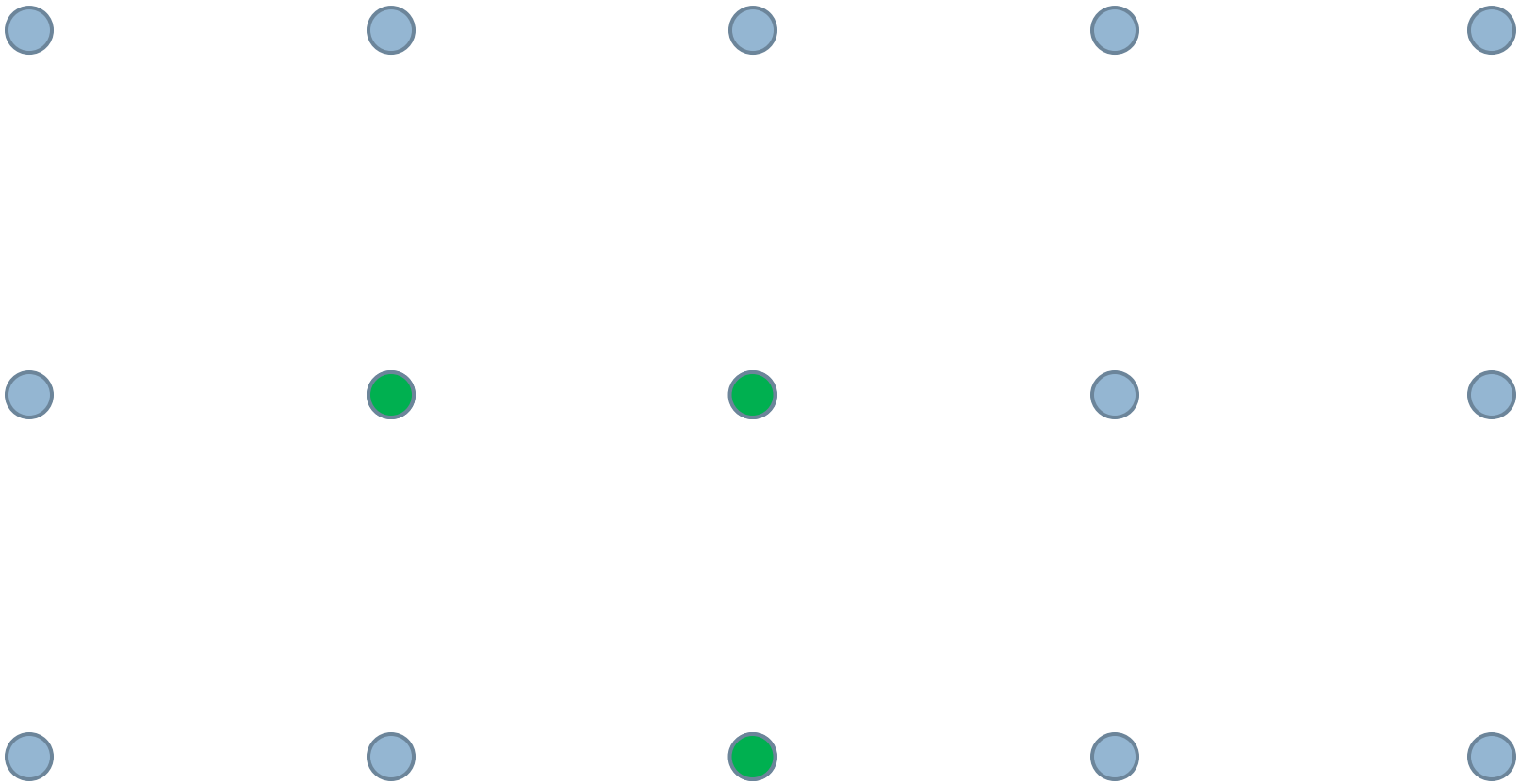

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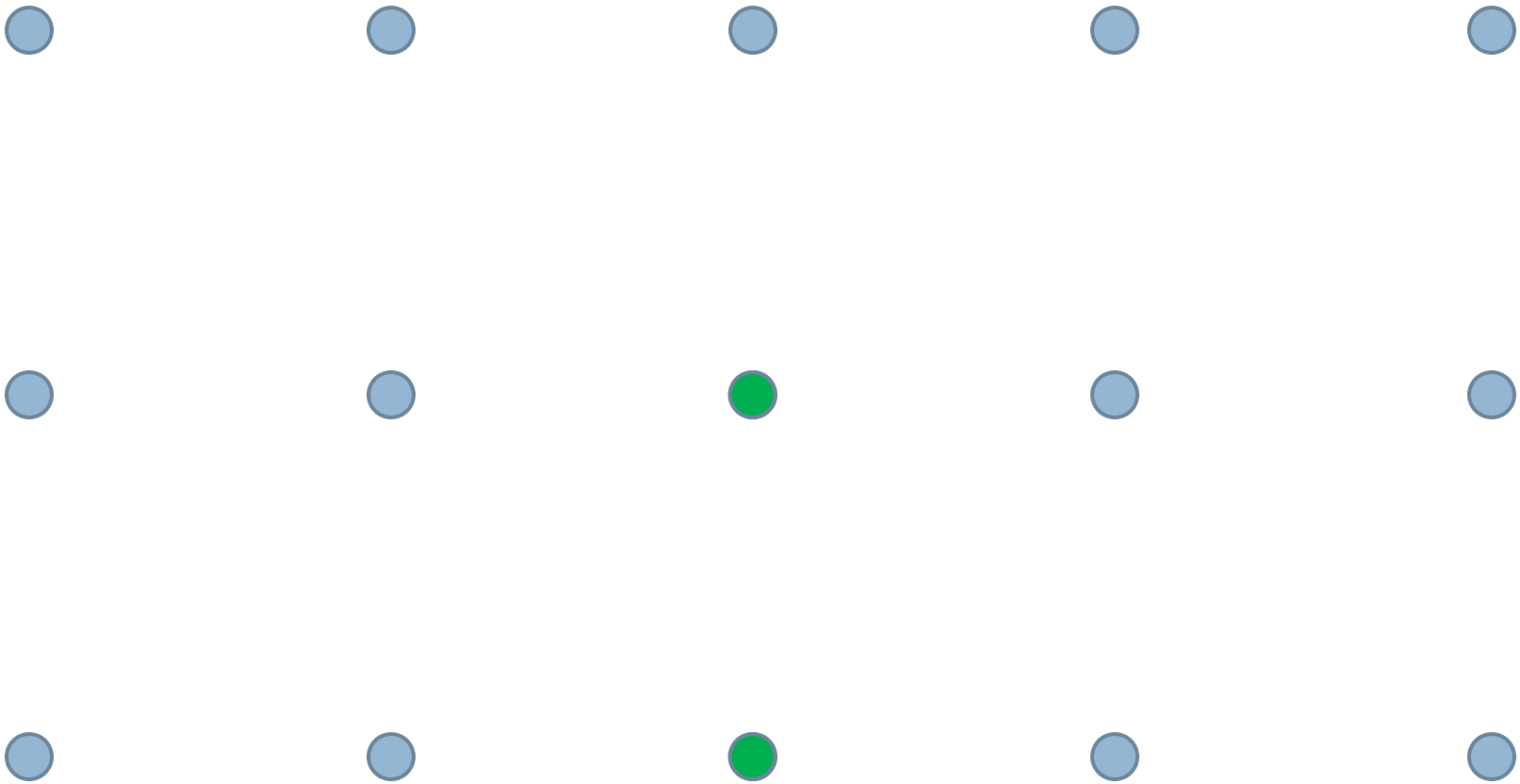

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