MLS

An Efficient Location Service for Mobile Ad Hoc Networks

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Geographic Routing

- To each message, piggyback the position of the receiver
- The routing decision is solely based on this information
  - **Greedy forwarding**: A node forwards a message to its neighbor closest to the destination
  - **Face routing**: To surround routing voids, a message may be routed along the border of the hole

Geographic Routing

- **Advantages of georouting**
  – No routing tables, efficient and scalable
  – No setup time, each new node can participate immediately
  – Fully reactive (on demand) routing

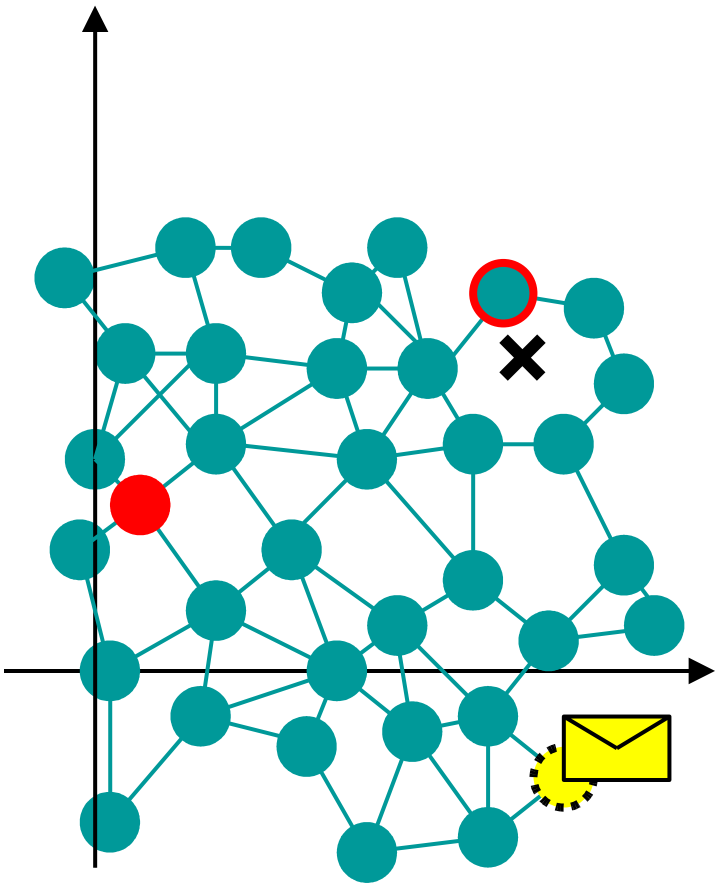
… once the position of the destination is known

Location Service

- **Q: How can a node determine the position of another node?**

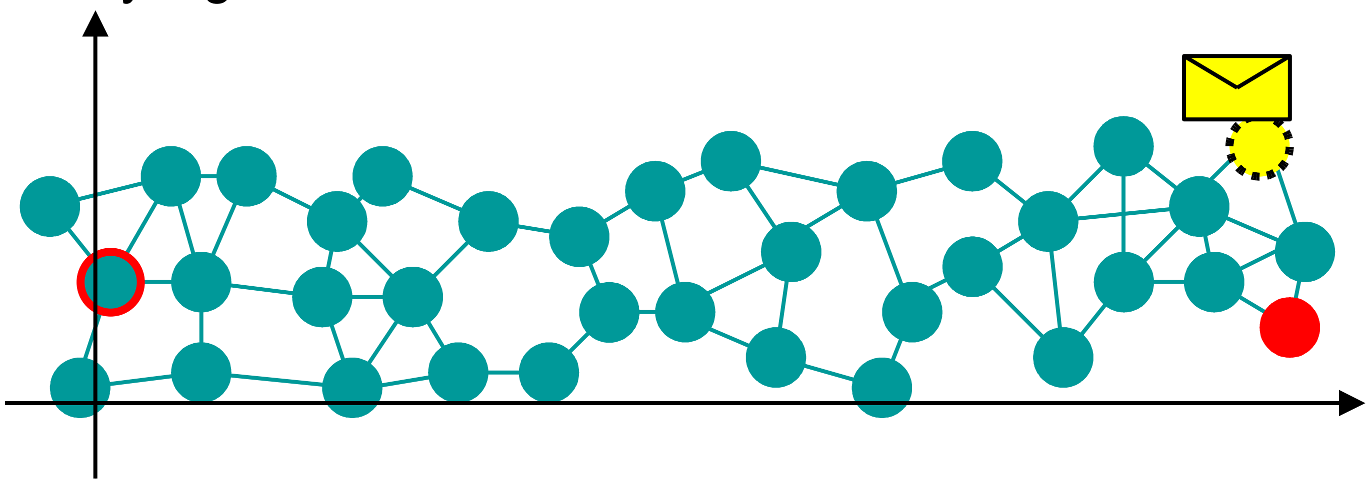
- **Proactive distribution**
  - Each node broadcasts its position
  - VERY expensive

- **Home based** location service
  - Each node has an associated place (its home) where it stores its location
  - The place is determined by the hash value of the node's ID
  - Any node can determine this place
  - This is a **GHT** (Geographic Hash Table)



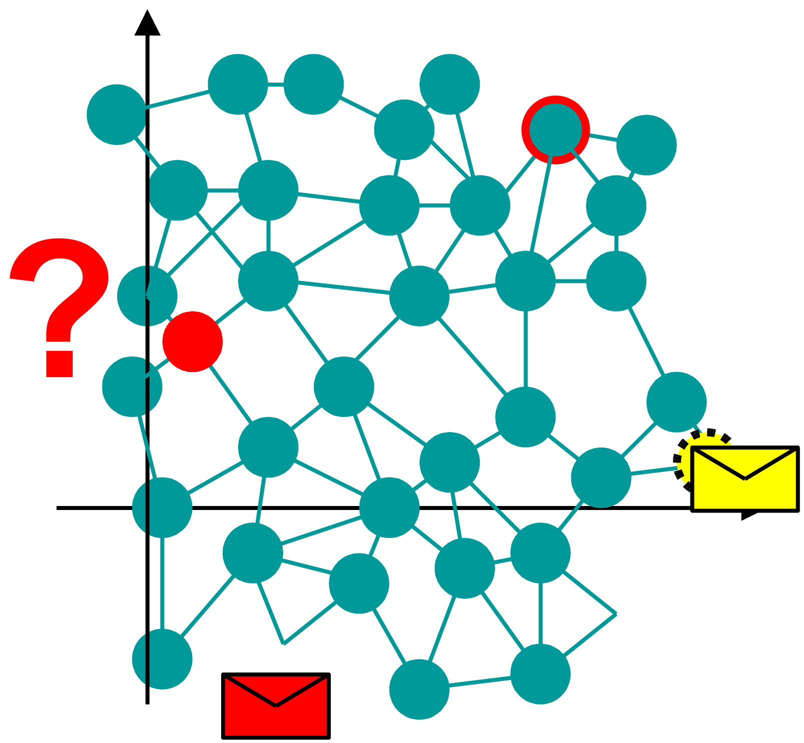
GHT: Home Based Location Service

- Each node has a single location server
  - Chosen at a random position
- Good load balancing
  - Each node has to store location information only for a few nodes
- Arbitrary high stretch:



Mobility

- Mobile nodes complicate location services tremendously
- The **position of a node cannot be known exactly**, as it may change continuously
- Any location information has to be considered **stale**
  - Lookup of position not wise, rather route messages through location server



Some Related Work in the field of Location Services

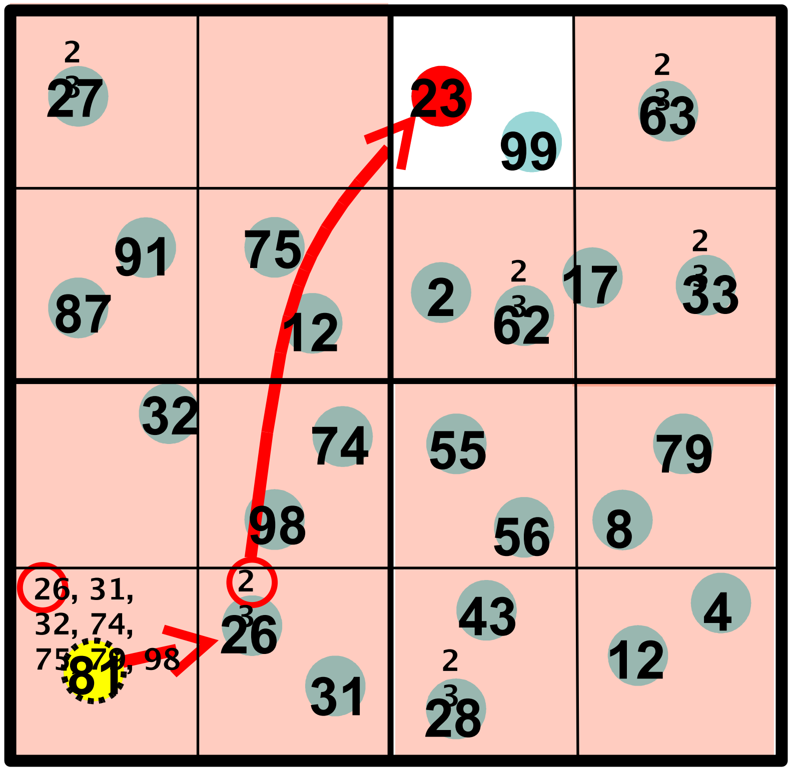
- **LLS**: "*LLS: A Locality Aware Location Service for Mobile Ad Hoc Networks*" by Abraham et al. @ DIALM-POMC 2004
- **GLS**: "*A Scalable Location Service for Geographic Ad Hoc Routing*" by Li et al. @ MobiCom 2000
- **DLM**: "*A Scalable Location Management Scheme in Mobile Ad Hoc Networks*" by Xue et al. in LCN 2001
- **HIGH-GRADE**: "*Enhancing Location Service Scalability with High-Grade*" by Yu et al. @ MASS 2005
- "*Scalable Ad Hoc Routing: The Case for Dynamic Addressing*" by Eriksson et al. @ InfoCom 2004
- "*Geographic Routing without Location Information*" by Rao et al. @ MobiCom 2003
- "*Topology Independent Location Service for Self-Organizing Networks*" by Rezende et al. @ MobiHoc 2005

Related Work (Excerpt) - GLS

- **GLS**: "*A Scalable Location Service for Geographic Ad Hoc Routing*" by Li et al. @ MobiCom 2000

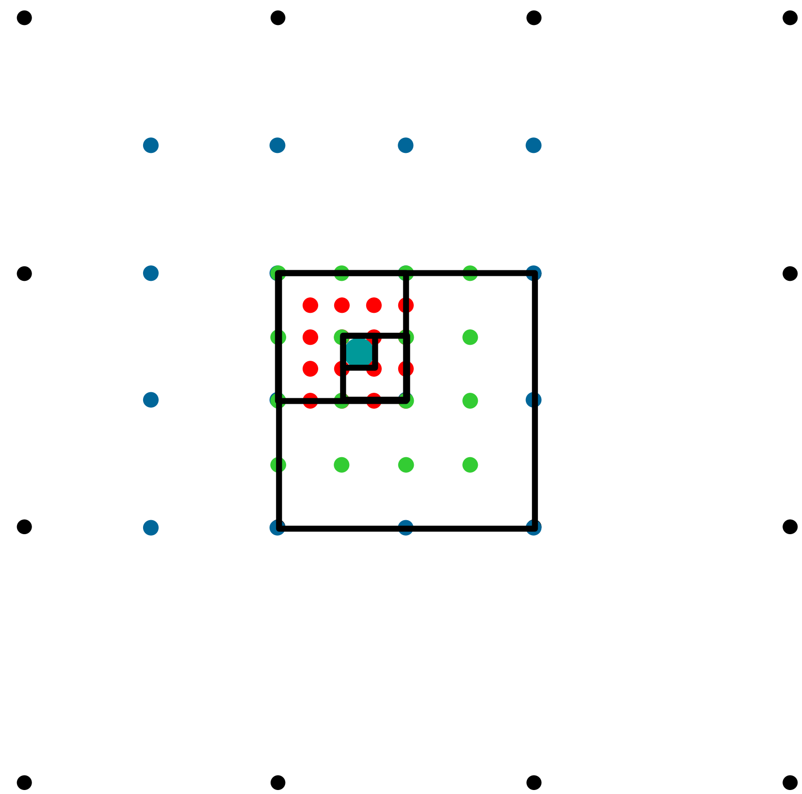
- **Lookup cost:** Size of the biggest surrounding square (level)

- **Publish cost:** not bounded



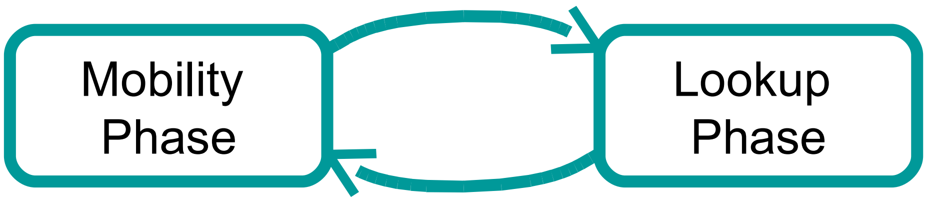
Related Work (Excerpt) - LLS

- **LLS**: "*LLS: A Locality Aware Location Service for Mobile Ad Hoc Networks*" by Abraham et al. @ DIALM-POMC 2004
- **Lookup cost:** O(d^2)
- **Publish cost (amortized):** O(d log d)



Mobility revisited

- GLS and LLS support mobile nodes, but not **concurrent lookup and mobility**
- Existing solutions assume that mobility and lookups do not interfere

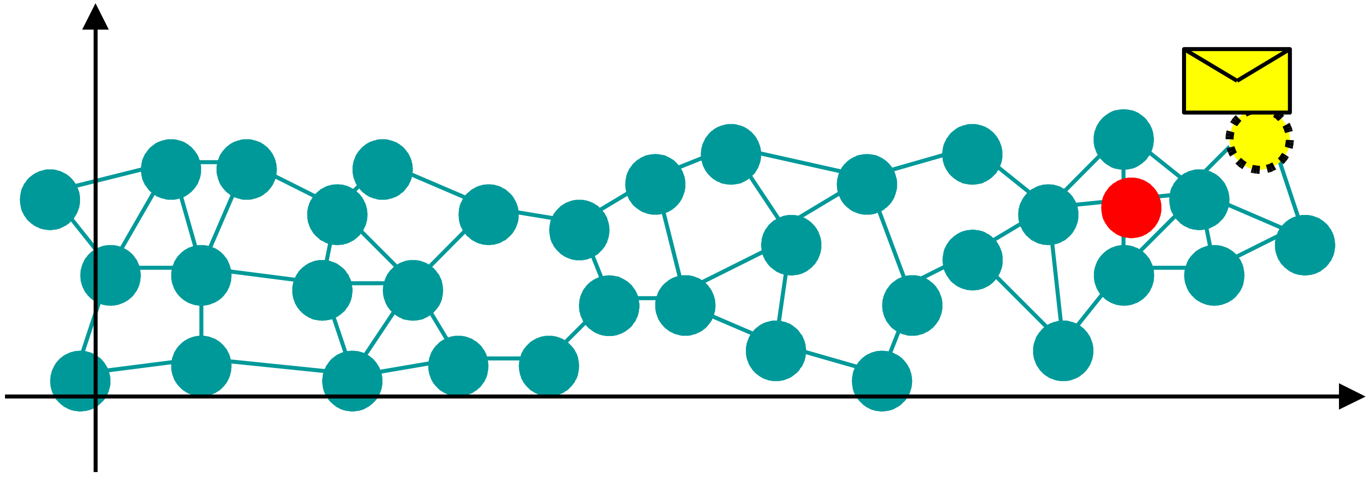


The nodes are mobile and update their location servers **XOR** The nodes perform lookups

- That's clearly not what we expect from a **M**ANET!
  - Nodes cannot move freely
  - Lookups / routing cannot happen concurrently
  - Synchronization would be required to switch between the two phases

Mobility – but limited

- Nodes may not move arbitrarily fast!
  - If a node moves faster than the message propagation speed, no routing algorithm can ensure delivery
- Thus, we must **limit the maximum node speed**
  - Maximum node speed can be expressed as a function of the message propagation speed of the underlying routing algorithm



Outline

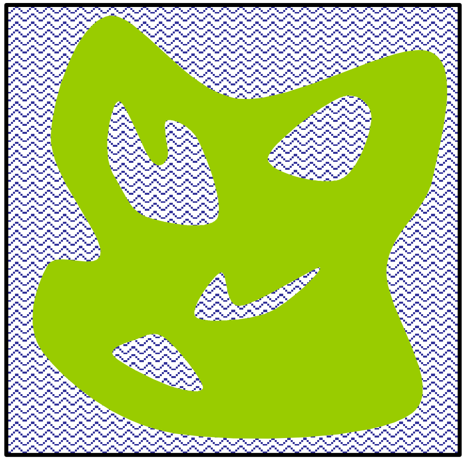
- **Motivation** for building location services
- **Mobility** and its issues
- **Related work**
- **MLS** our contribution
- **Model**
- **Algorithm & Analysis**
- **Conclusion**

MLS – Location Service for Truly Mobile Nodes

- The lookup service works despite of **concurrent mobility**
  - Nodes may move freely at any time and anywhere
  - Lookup and routing requests may execute at any time
- Routing is performed through the lookup mechanism
  - No stale location information
- **Lookup / routing overhead**: close to optimal
  - Routing to a node costs O(d), where d is the distance
- Moderate **publish overhead** due to mobility
  - Amortized bit-meter cost is O($d \log d$) for moving a distance d
- Quite **fast moving nodes**!
  - Nodes may move up to 1/15 of the message propagation speed
  - On arbitrary paths

Model

- **Deployment Area**
  - Nodes populate land areas
  - Lake denote holes
  - Connected graph, no islands
- **Connectivity**
  - n_1, n_2 are connected if $d(n_1, n_2) \leq r_{min}$
- **Density**
  - For any point on land, there exists a node at most r_{min} / 3 away
  - Thus, relatively dense node deployment
- **Node Equipment**
  - Position module (GPS, Galileo, local system, …)
  - Communication module
- **Underlying Routing**
  - Given a destination position p_t, we can route a message in $\eta\, d(p_s, p_t)$ from the sender position p_s to p_t



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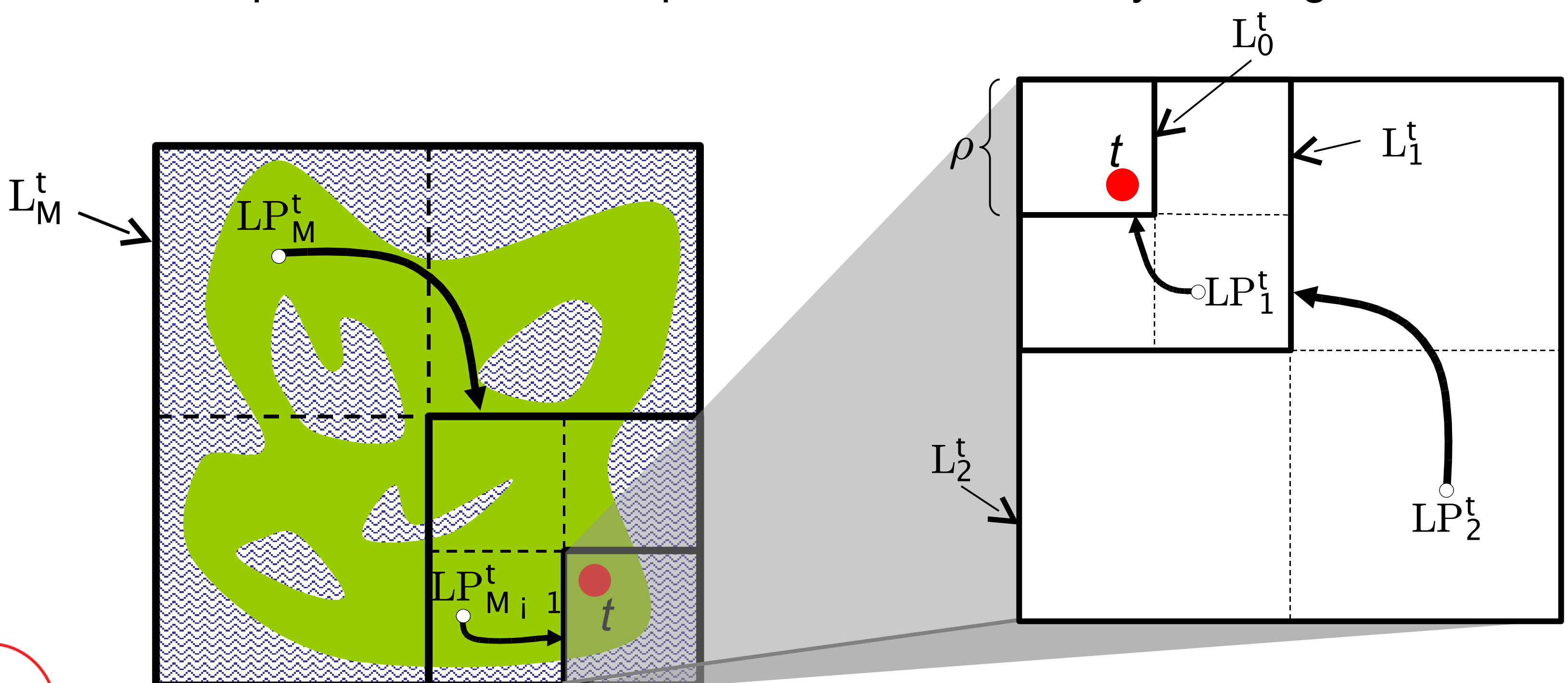
Selection of Location Servers

- Each node builds a hierarchy of location servers that are located in exponentially increasing areas around the node.
  - Top **level** surrounds entire world
  - Each level is divided in 4 sub-squares
  - A **level pointer** points to the next smaller level that surrounds *t*
  - The position of the level pointer is determined by hashing the ID of *t*

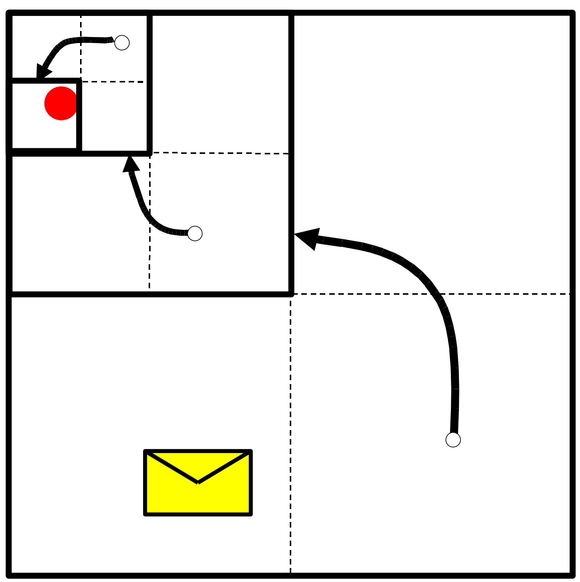


Routing in MLS

- Routing in MLS consists of two phases

1) Find a Location Pointer of the destination
2) Recursively follow the Location Pointers

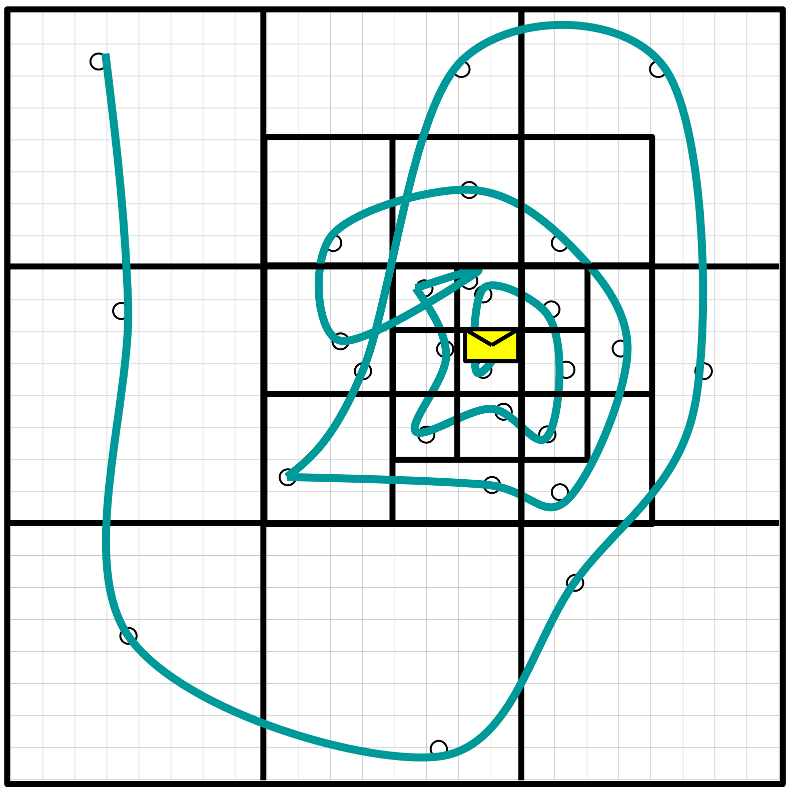
- The second step pretty easy:



Performance
If the destination is *d* away from sender, the lookup path is O(*d*).

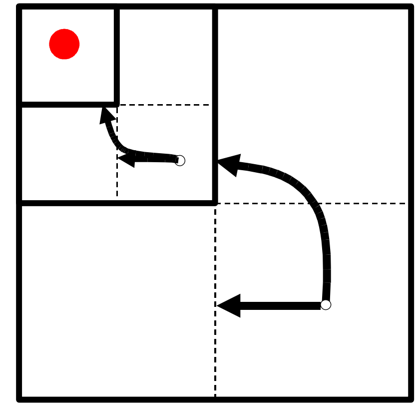
How to find a Location Pointer

- First, the sender assumes that the destination is in its vicinity
- While the lookup request fails to find a location pointer, it increases the search area

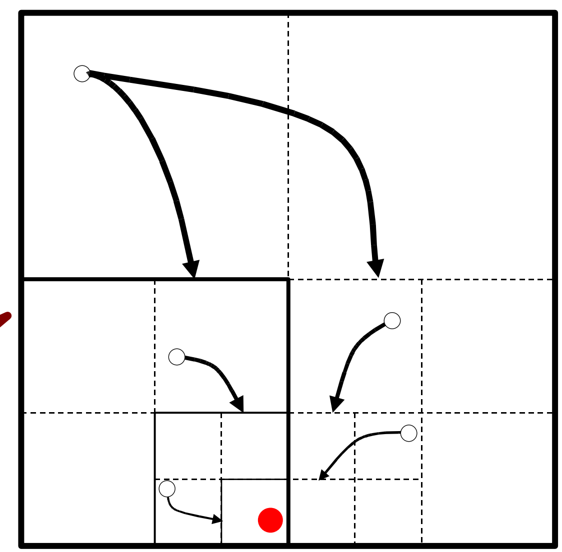


Performance
If the destination is *d* away from sender, the lookup path to *find a first location pointer* is O(*d*).

Supporting Mobility



- A location pointer only needs to be updated when the node leaves the corresponding sub-square.
- *Most of the time*, only the closest few location pointers need to be updated due to mobility
- **Not enough to guarantee low publish overhead!**
  - If node oscillates over grid-boundary of several layers, *many* location pointers need to be updated.

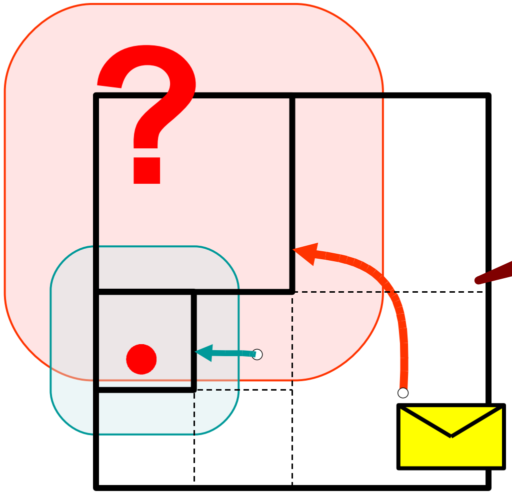


Unbounded publish cost!

Lazy Publishing

- To overcome exorbitant publish cost due to oscillating ε–moves:

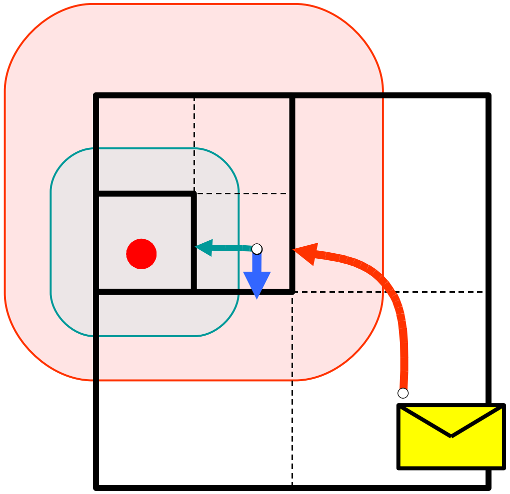
Only update a location pointer if the node has moved away quite a bit



Breaks the location pointer chain!

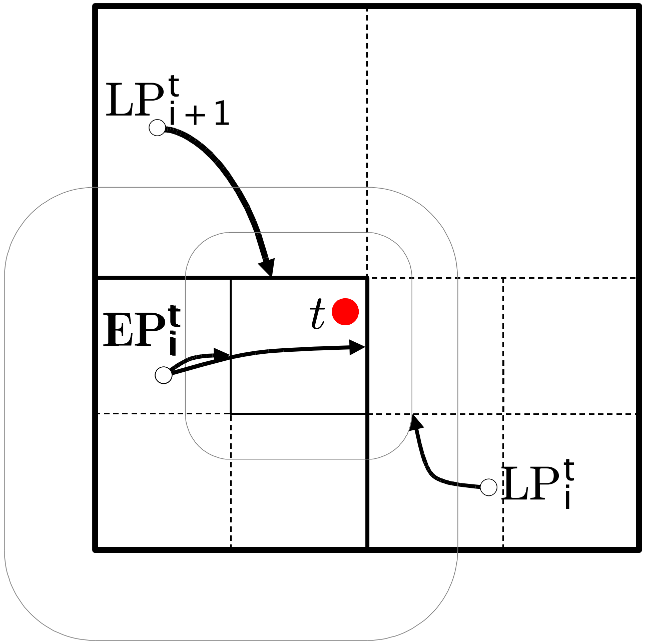
Lazy Publishing with Forwarding Pointers

- To repair the lookup path, add a **forwarding pointer** that points to the neighboring level that contains the location pointer.



Supporting Concurrency

- Allowing for **concurrent lookup requests and node mobility** is somewhat tricky



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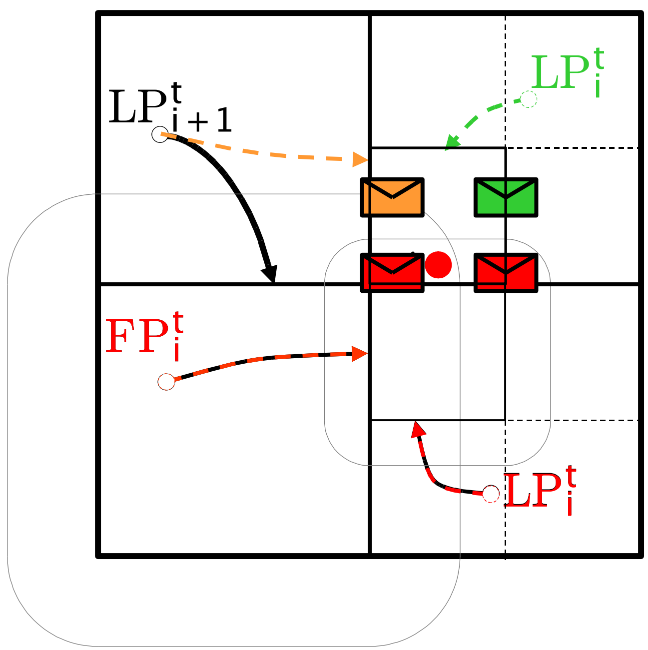
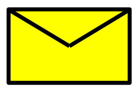
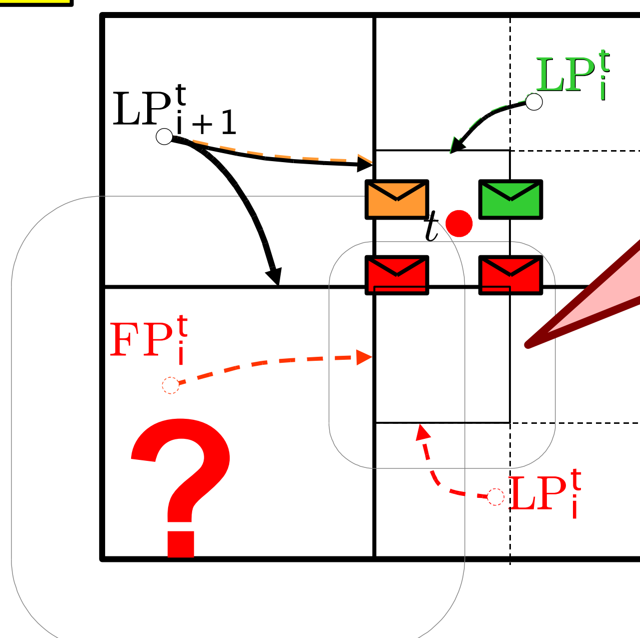


Supporting Concurrency

- Allowing for **concurrent lookup requests and node mobility** is somewhat tricky
  - Especially the *deletion* of location pointers and forwarding pointers
- **Routing of messages needs time**
  - Sending a message to the next location pointer
  - Sending command messages to update / delete / create a location pointer





Note:
These problems arise independently of the node speed.

Supporting Concurrency – TFP

- Solution to overcome the concurrency issue:

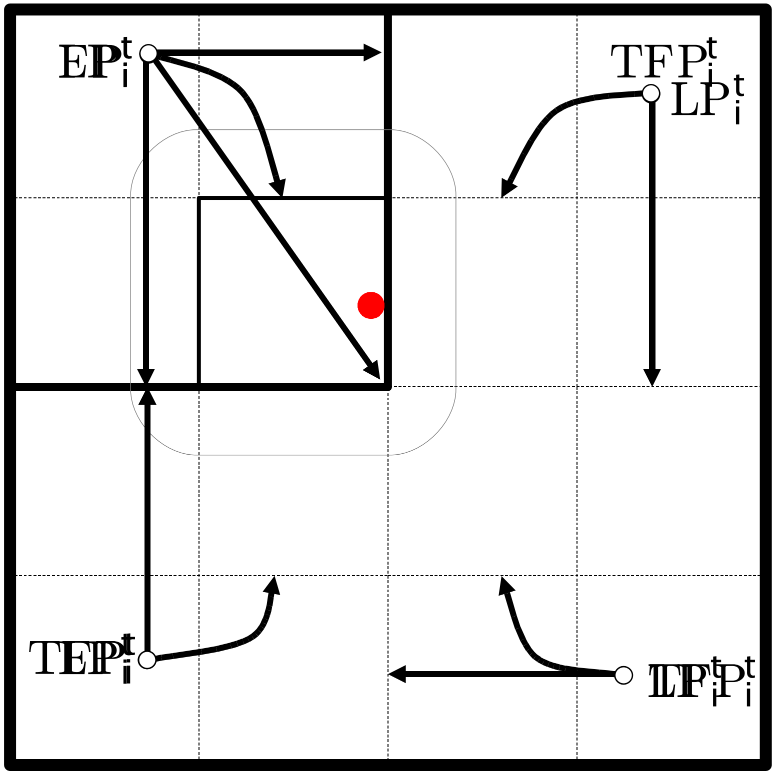
Do not delete a location or forwarding pointer, but replace it with a Temporary Forwarding Pointer (TFP)

- A temporary pointer redirects a lookup to the neighbor level where the node is located.

TFP are temporary and must be removed after a well known time.

Speeding

- A mobile node may generate many forwarding pointers while a lookup searches for it
  - If the lookup is not fast enough, it permanently follows forwarding pointers



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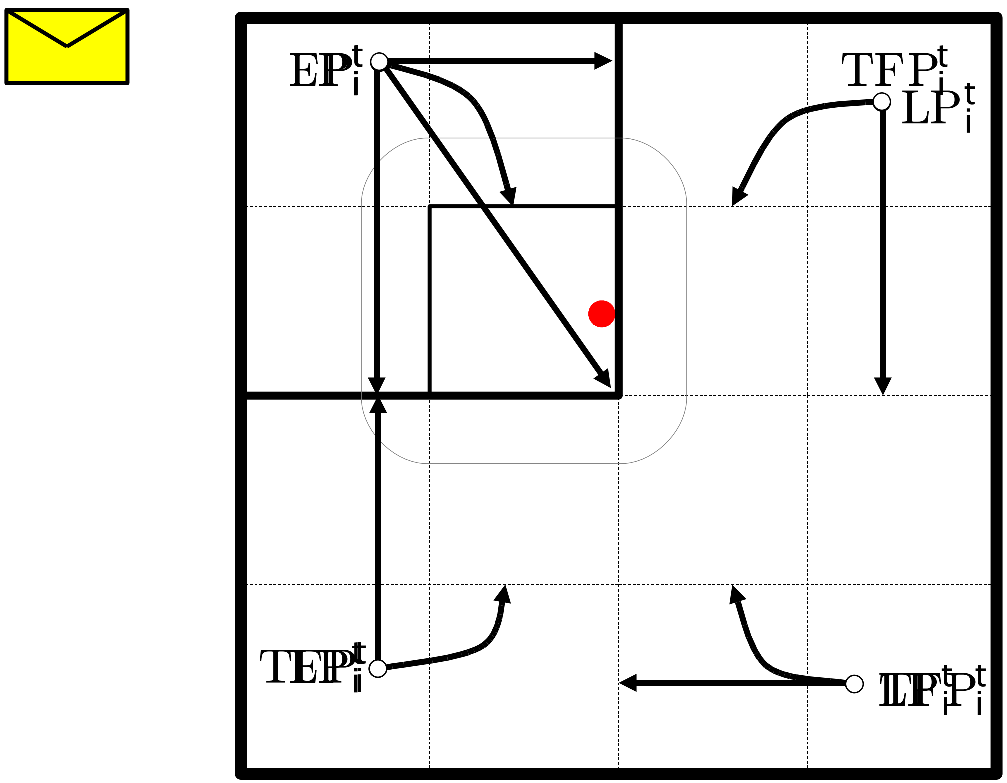

Performance of MLS

- The **maximum node speed** depends on several parameters
  - Min. speed of underlying routing
  - Lazyness in lazy publishing
  - How long we are willingly to follow temporary and forwarding pointers of a moving node

- […] Without lakes, the maximum node speed m… of the minimum message speed of the underlying …

Please see paper for details…

$$v_{node} \leq \frac{v_{msg}}{15}$$

- Despite of this relatively high node speed
  - **Lookup cost is O(*d*)**
  - **Amortized publish cost is O(*d* log *d*)**

Thank you!

Questions / Comments?

Distributed
Computing
Group

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BACKUP

- Publish Algorithm
- Lookup Algorithm
- Nomenclature
- GLS (Related work)
- LLS (Related work)
- LLS WC

Publish Algorithm

if($\delta_i^t \geq \alpha \cdot \rho \cdot 2^i$) {
    if(i>0) {change FP_i^t in $^*\mathrm{LP}_{i+1}^t$ to TFP_i^t;}
    if($\mathrm{LP}_{i+1}^t \in \mathrm{L}_{i+1}^t$) {
        change LP_{i+1}^t to point to L_i^t;
    } **else** {
        if($\mathrm{LP}_{i+1}^t \in {}^*\mathrm{LP}_{i+2}^t$) {
            change LP_{i+1}^t to FP_{i+1}^t that points to L_{i+1}^t;
        } **elseif**($\mathrm{L}_{i+1}^t = {}^*\mathrm{LP}_{i+2}^t$) {
            change LP_{i+1}^t to TFP_{i+1}^t that points to L_{i+1}^t;
        } **else** {
            change LP_{i+1}^t to TFP_{i+1}^t that points to L_{i+1}^t;
            change FP_{i+1}^t to point to L_{i+1}^t;
        }
        on L_{i+1}^t, add LP_{i+1}^t that points to L_i^t;
    }
    if(i>0 **and** $\mathrm{LP}_i^t \notin \mathrm{L}_i^t$) {
        add FP_i^t on L_i^t that points to $\mathrm{L}_i \ni \mathrm{LP}_i^t$;
    }
}

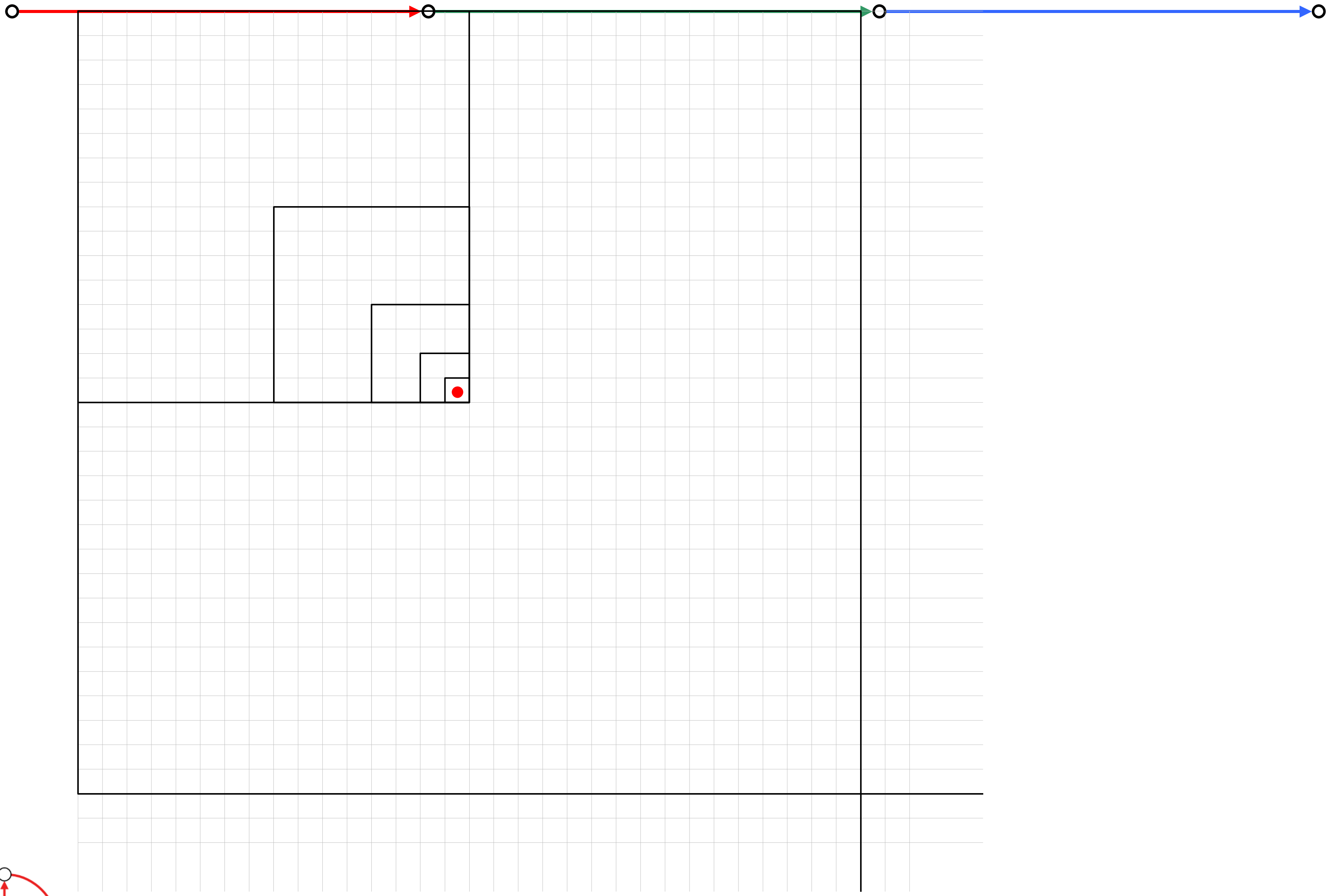
Lookup Algorithm

if($t \in \mathrm{L}_0^s \cup (\mathrm{L}_0^s)^8$) { exit(); }
for(i=1; **true**; i++) {
    if($P_i^t \in \mathrm{L}_i^s \;||\; P_i^t \in (\mathrm{L}_i^s)^8$) {
        $p = P_i^t$;
        break;
    }
}
Follow p until LP_1^t is reached.
Route to a node closest to an arbitrary point on land in $^*\mathrm{LP}_1^t$.
Forward to t.

Nomenclature

L_i^t	Level that contains t with side-length $\rho \cdot 2^i$
$(\mathrm{L}_i^s)^8$	The 8 surrounding squares of L_i^s
LP_i^t	Level pointer on L_i for node t; points to L_{i-1}
$^*\mathrm{LP}_i^t$	The L_{i-1} where LP_i^t points to
δ_i^t	distance of a node t to $^*\mathrm{LP}_{i+1}^t$
FP_i^t	Forwarding pointer if $\mathrm{LP}_i^t \notin {}^*\mathrm{LP}_{i+1}^t$
$^*\mathrm{FP}_i^t$	The L_i where $^*\mathrm{FP}_i^t$ points
TFP_i^t	Temporary forwarding pointer, before a pointer to t is removed
$^*\mathrm{TFP}_i^t$	The L_i where TFP_i^t points
TTL_i	Time to live of a TFP_i
v_{max}^{node}	Max. speed of nodes
r_{min}	Min. communication range of a node
λ	Min. distance to a node from any land point
ρ	Side length of L_0; $\rho = \lambda/\sqrt{2}$
M	L_M surrounds the entire world
α	When $\delta_i^t \geq \alpha \cdot \rho \cdot 2^i$, LP_{i+1}^t is updated
$\beta(\beta_T)$	Max. number of forwarding hops to reach LP_i^t from a FP_i^t (TFP_i^t)
γ	See Lemma 8.2
η	Routing overhead to route to a given position

LLS Worst Case



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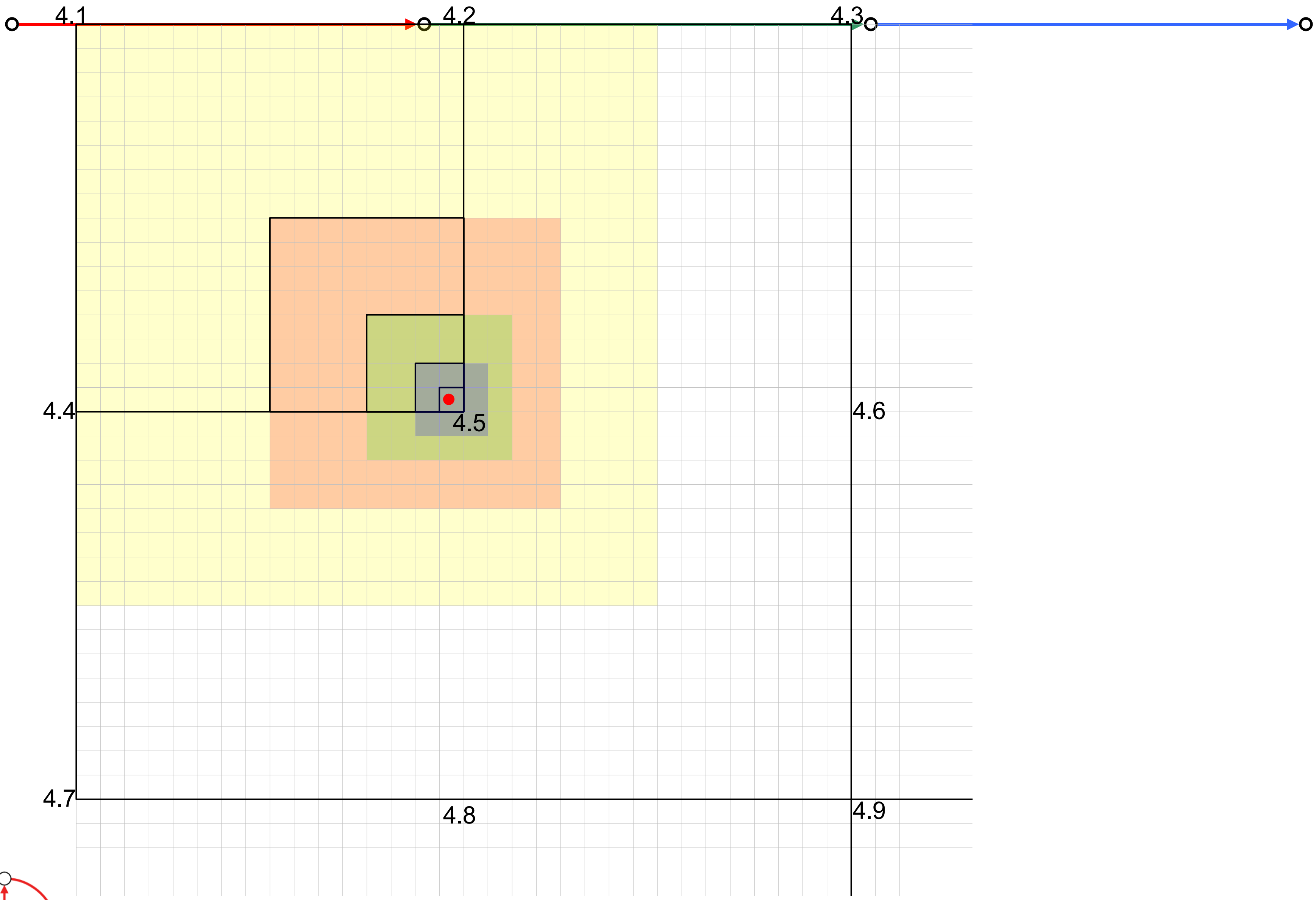

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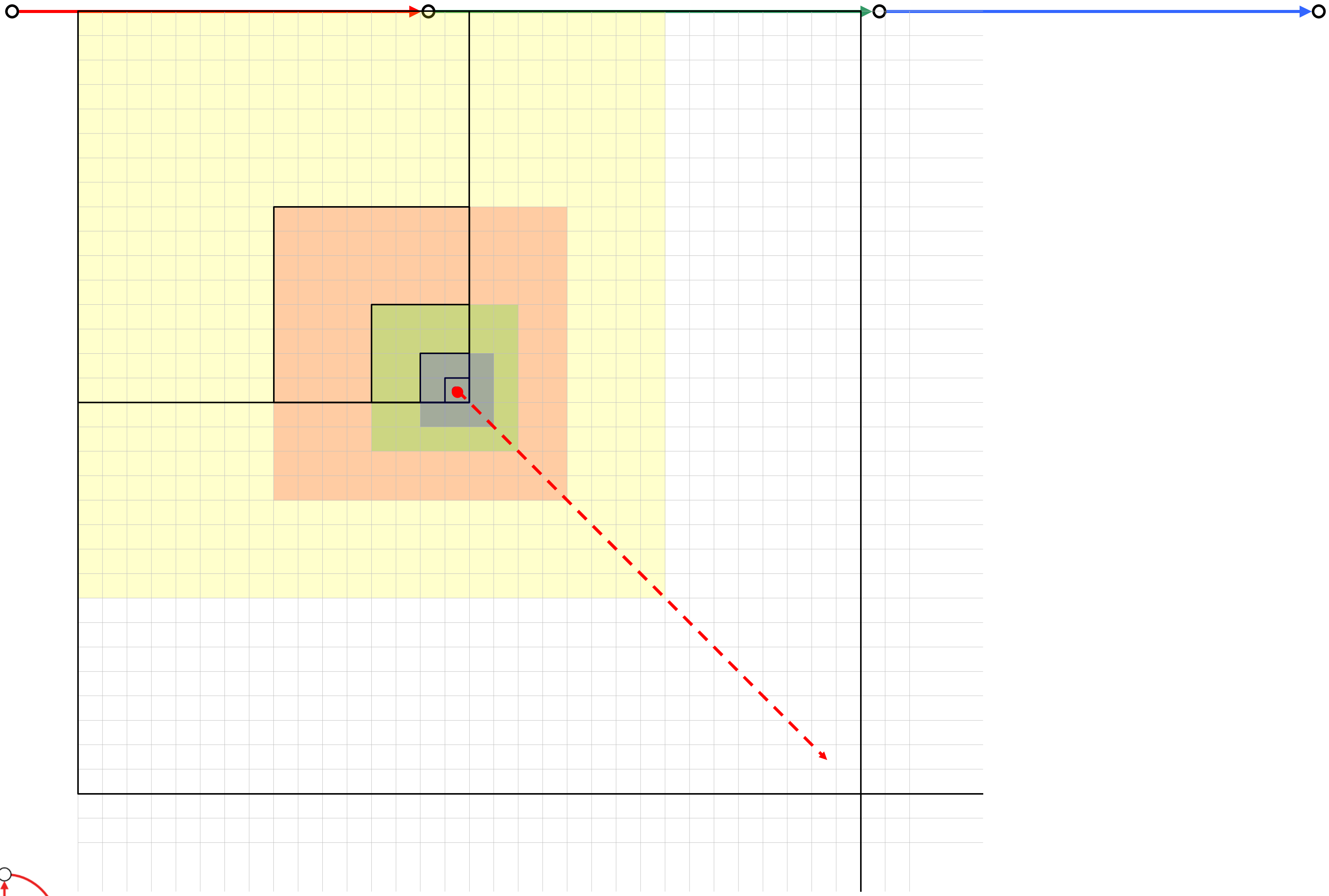

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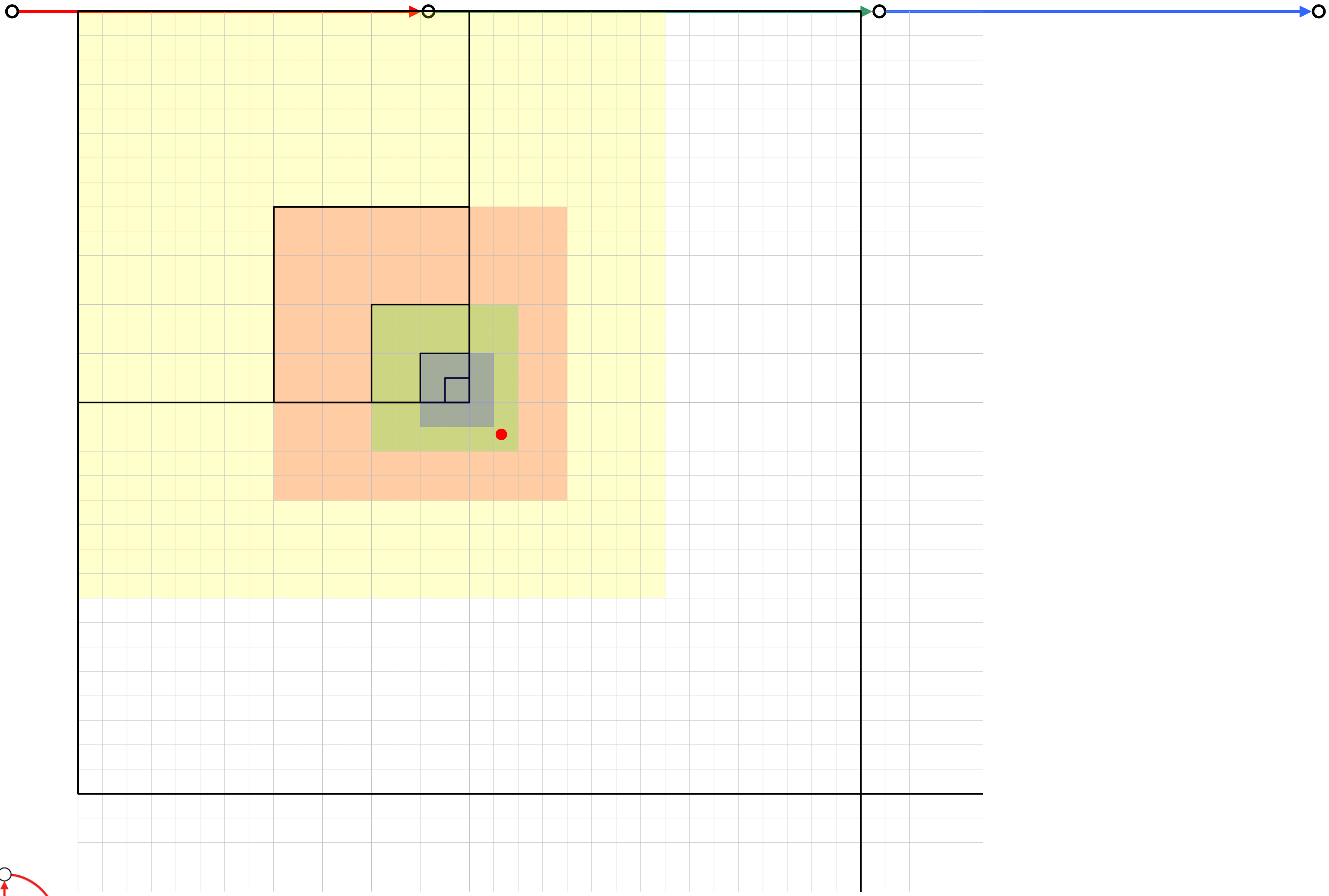

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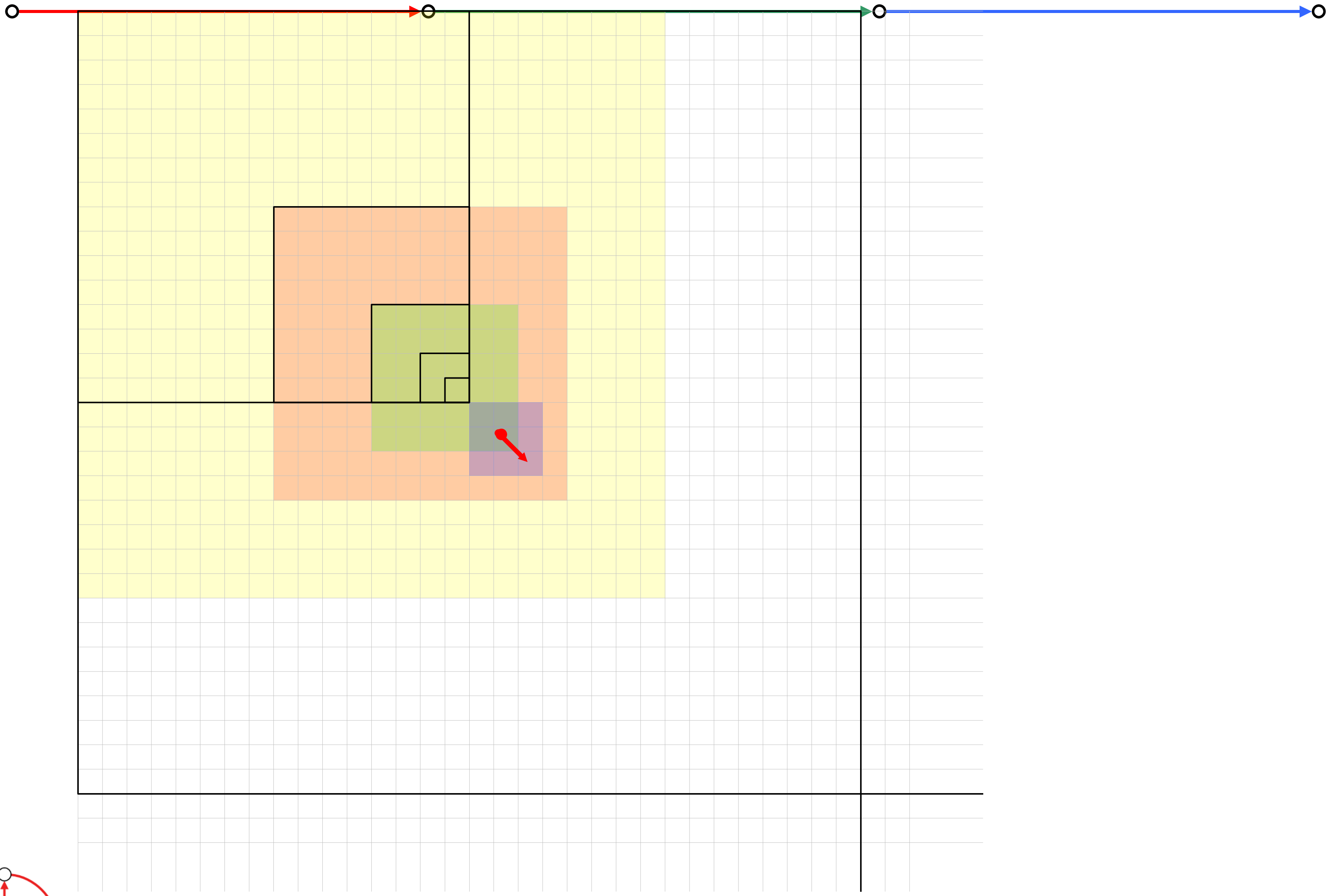

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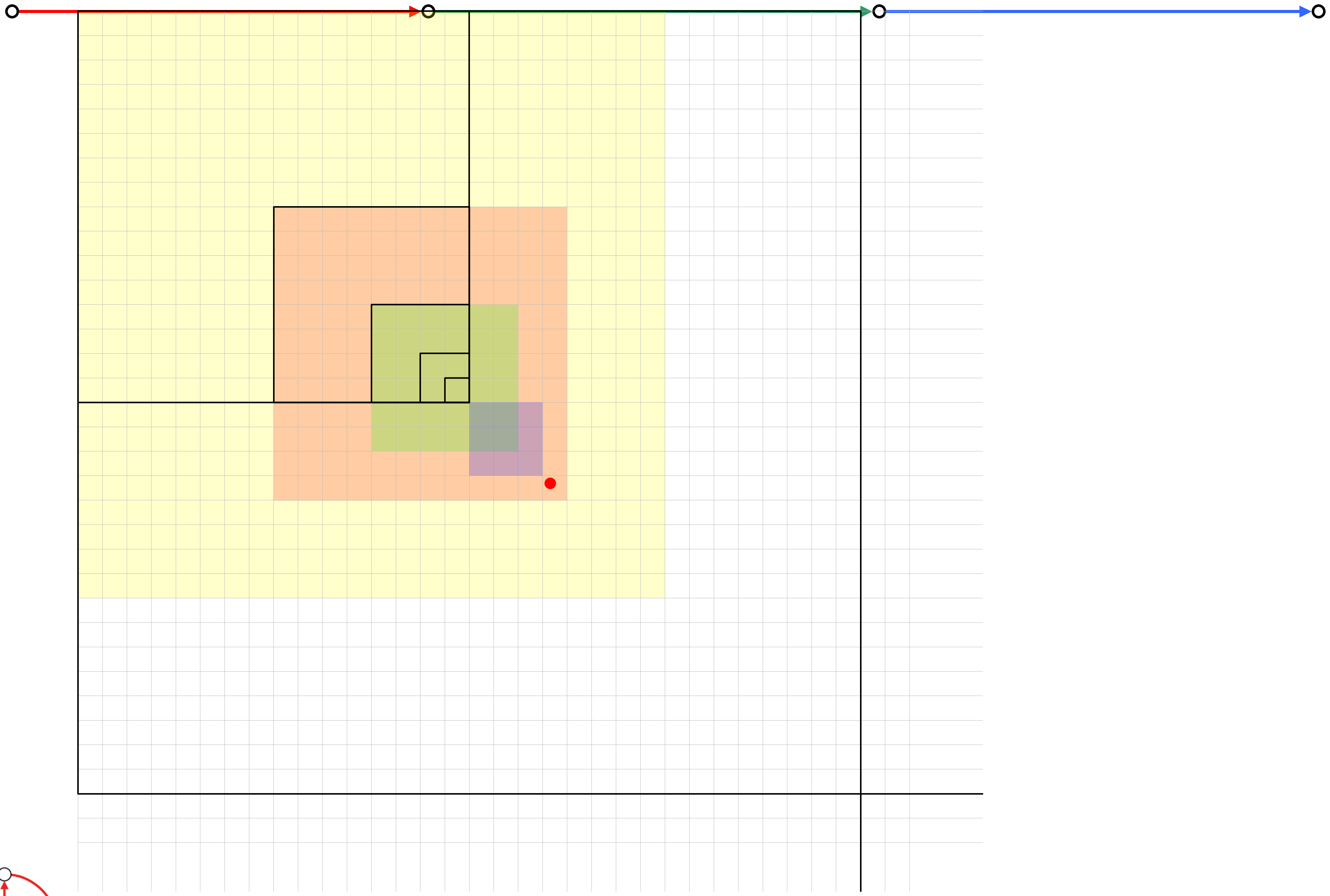

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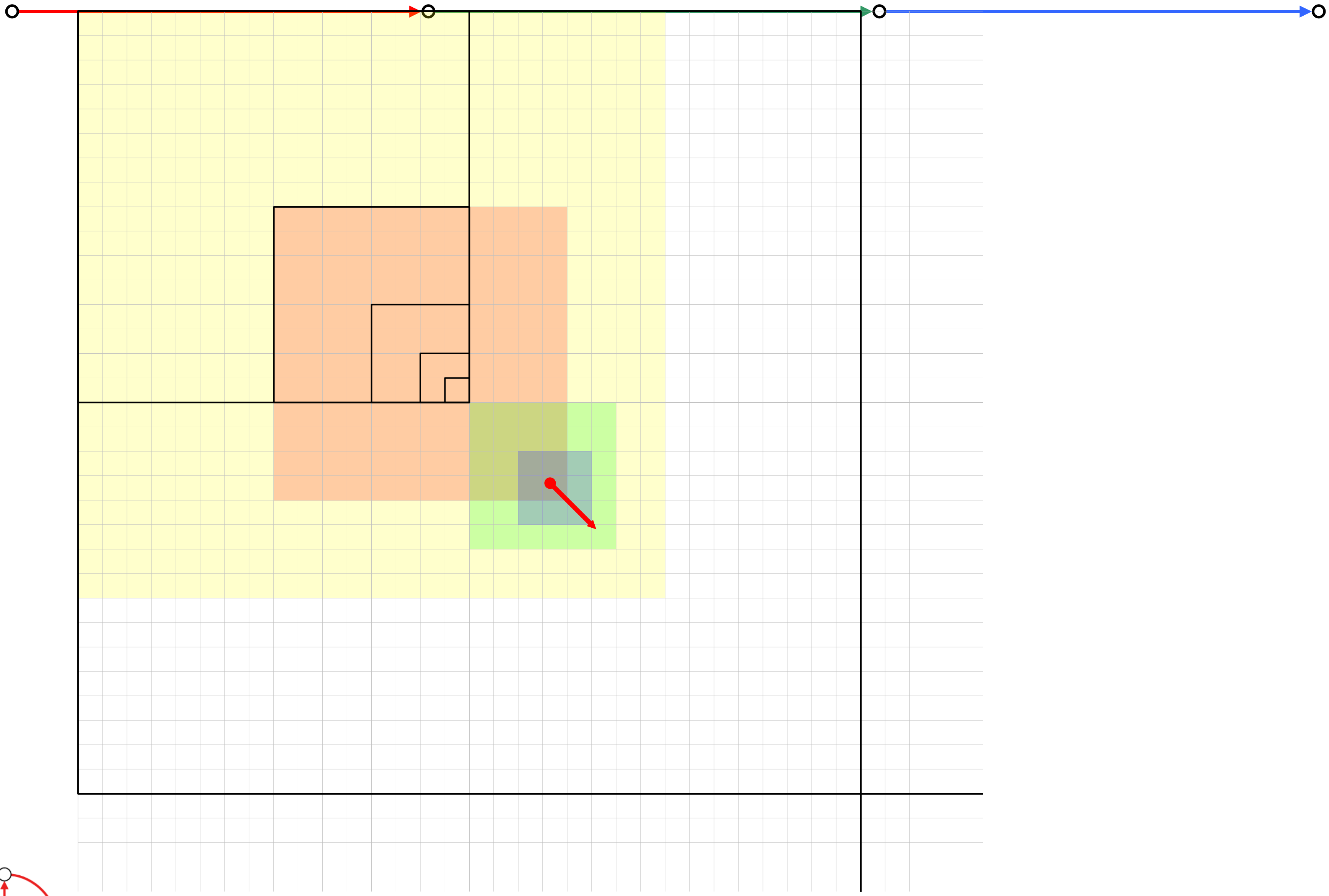

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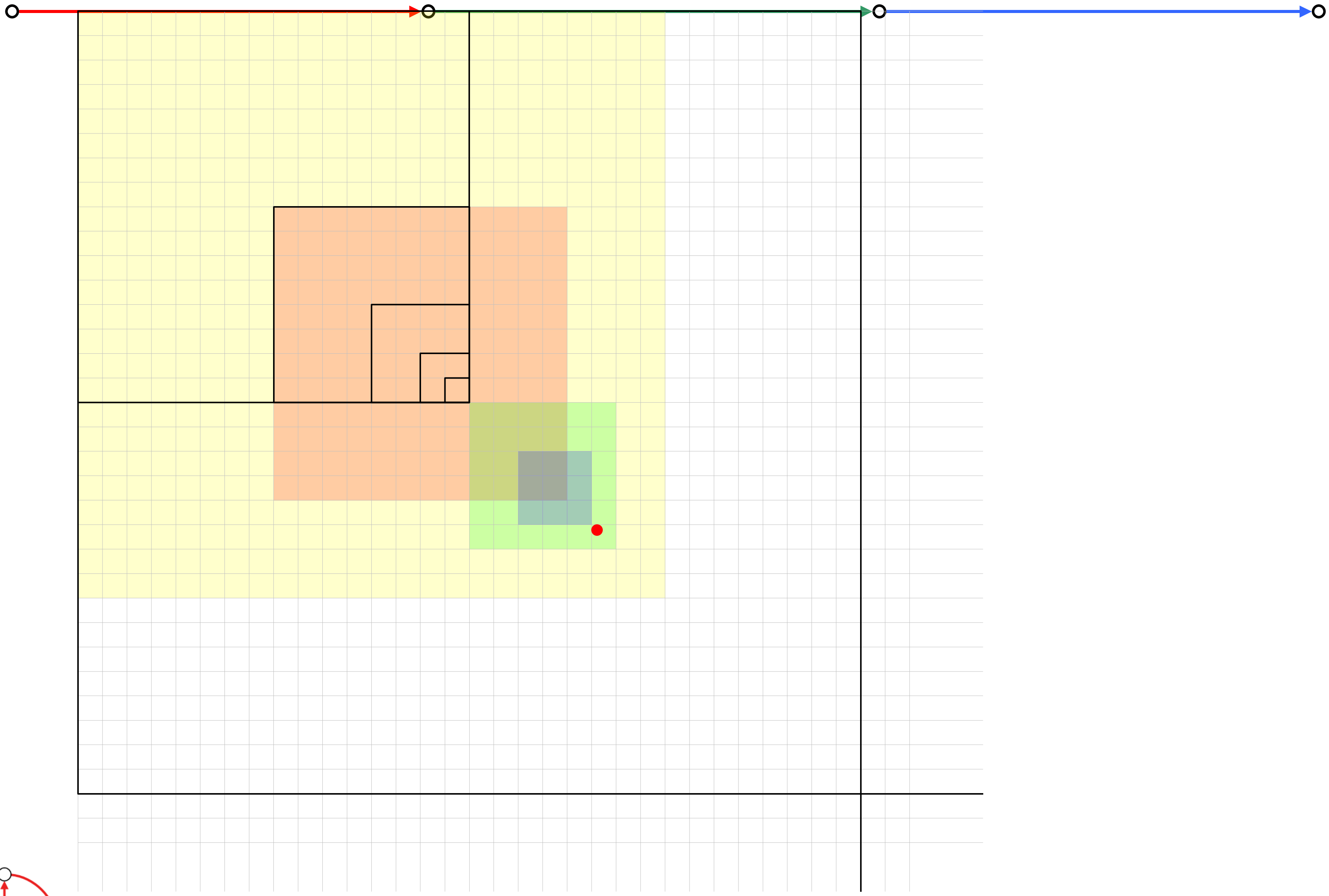

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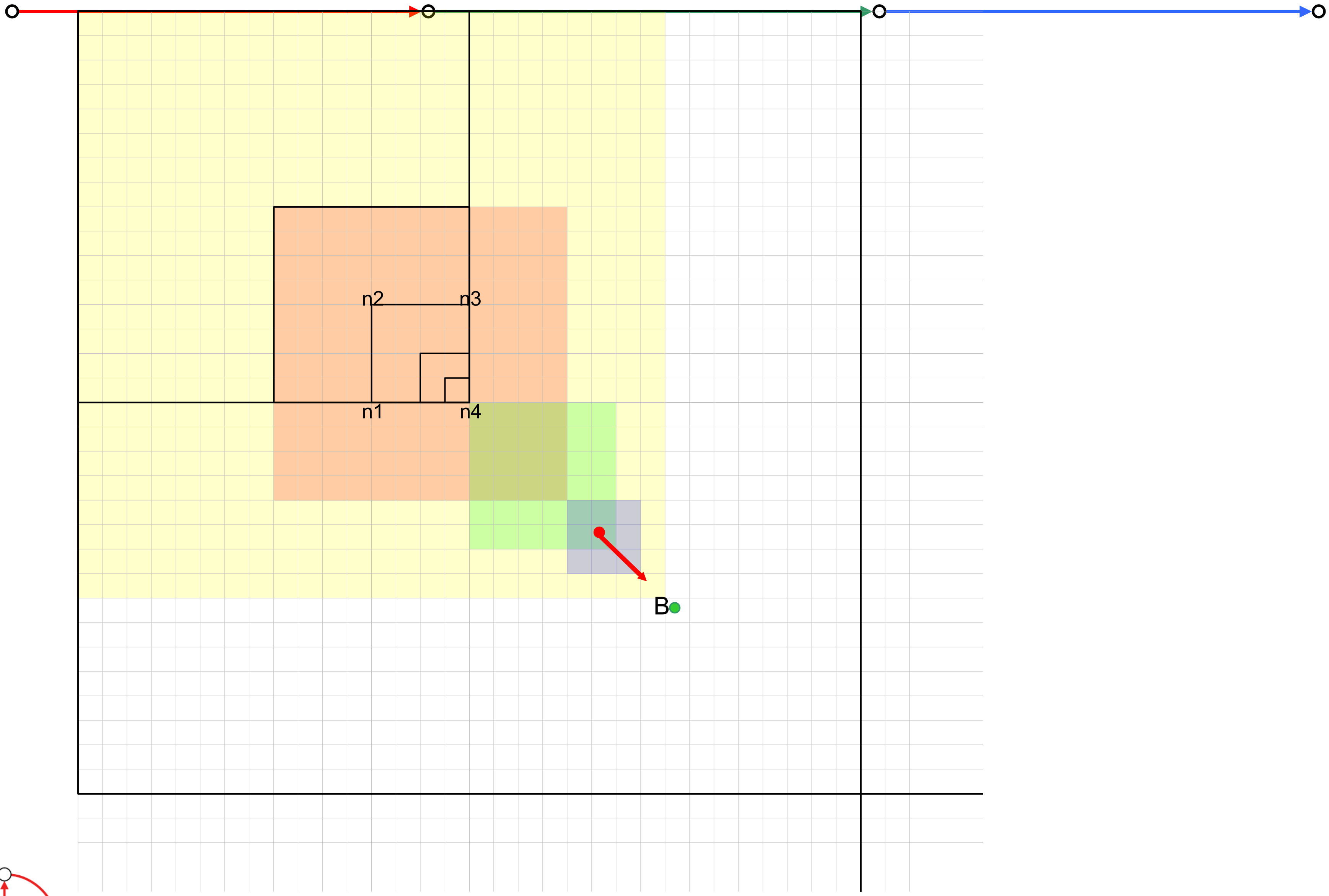

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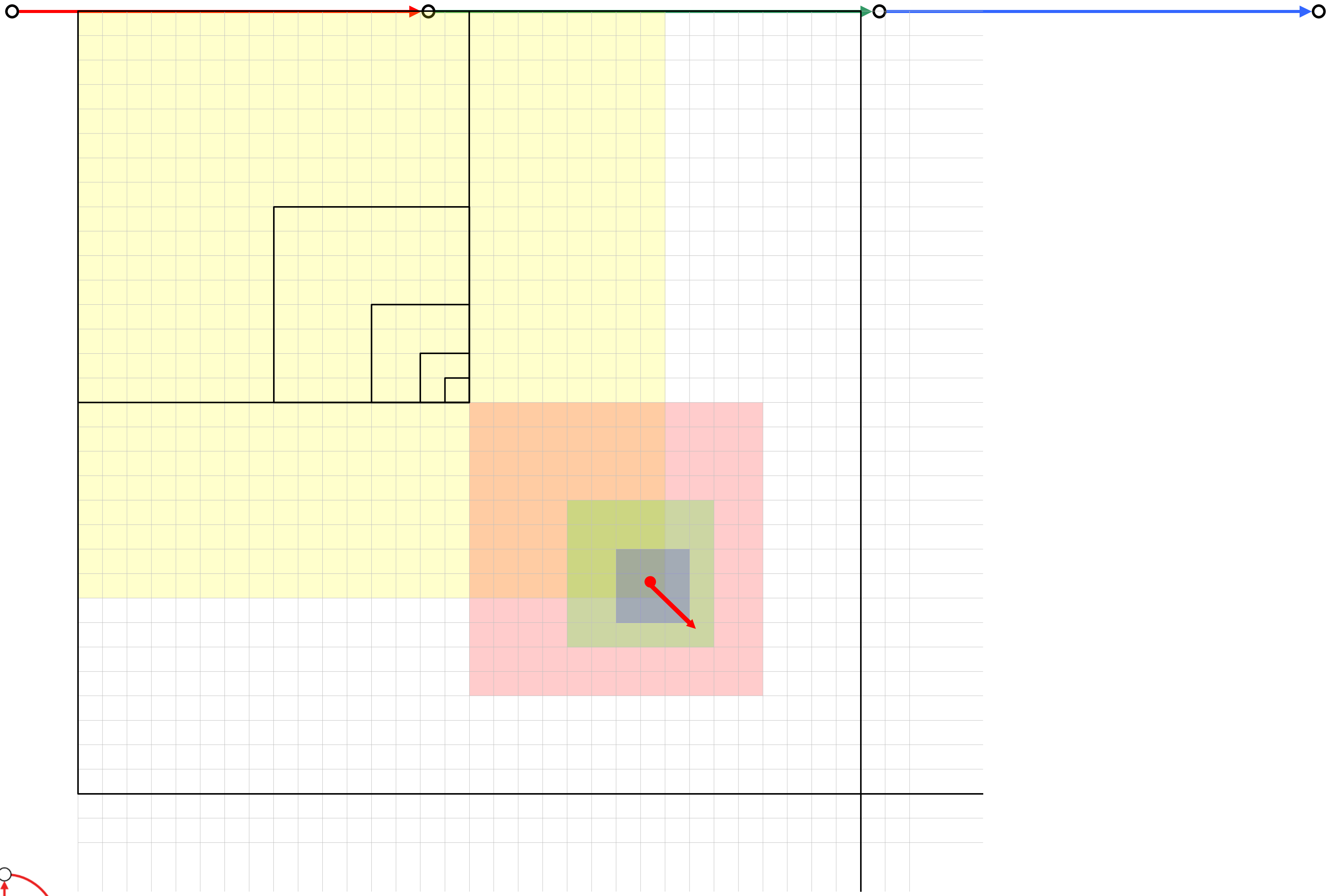

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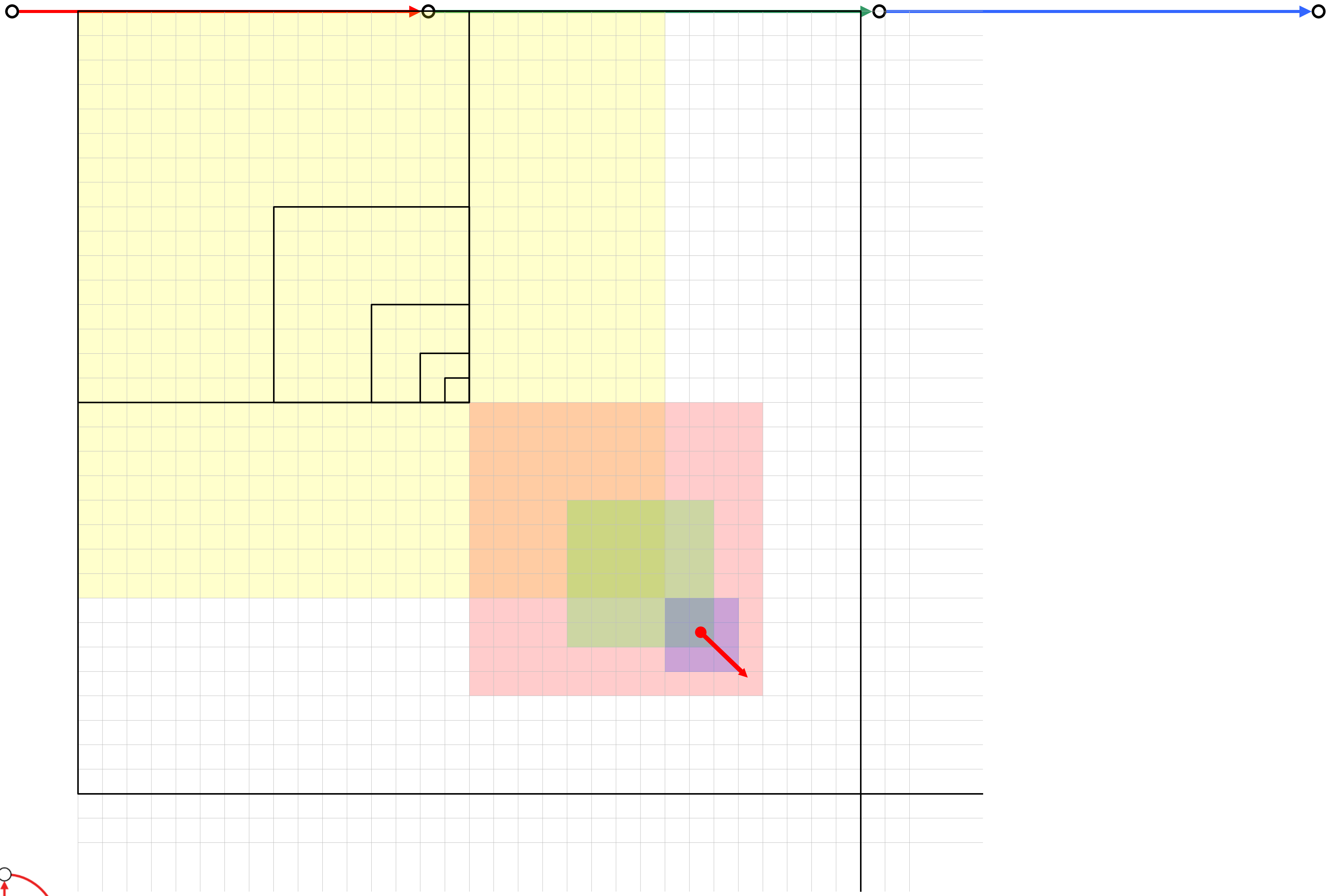

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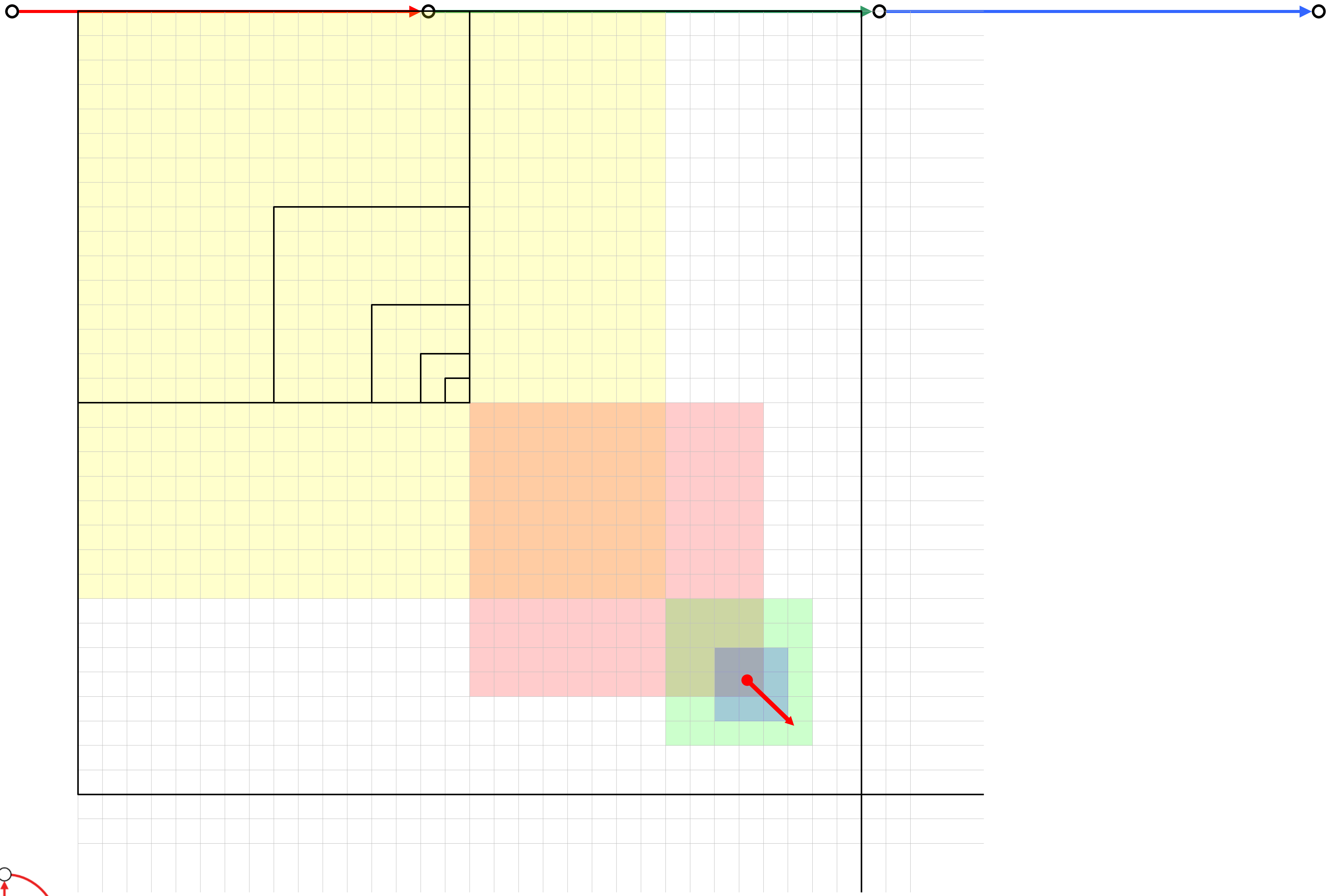

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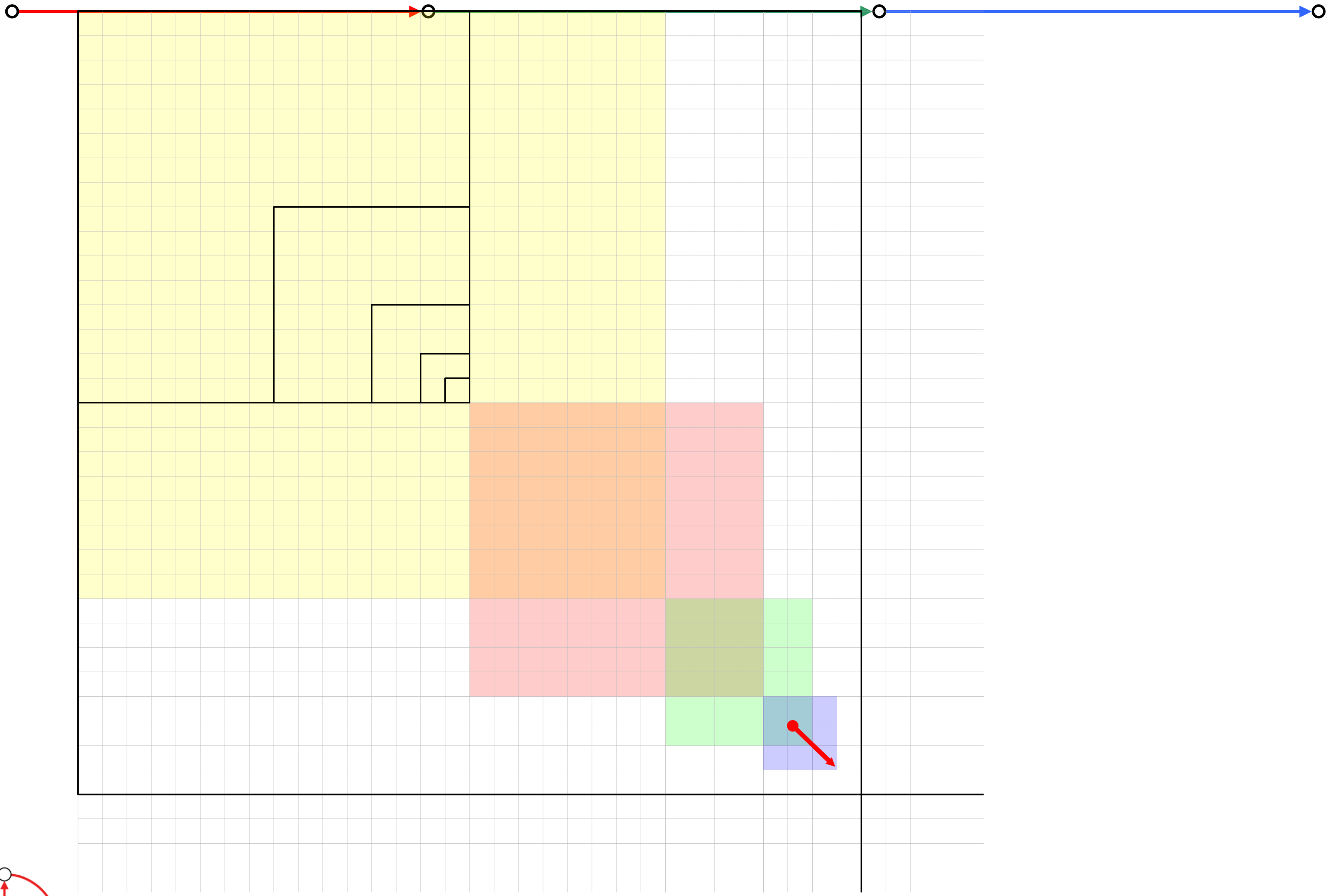

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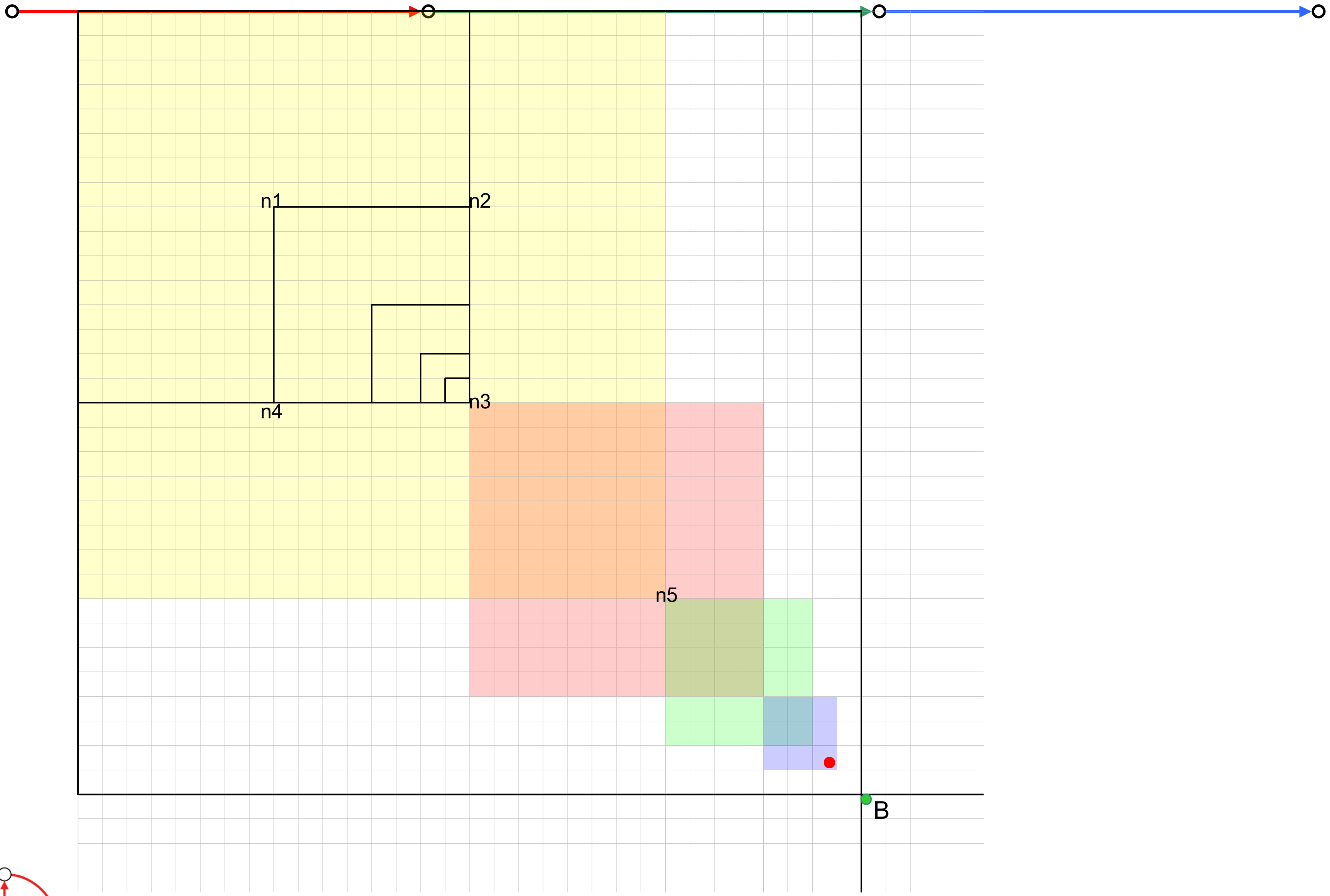

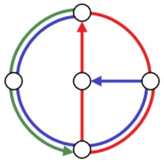

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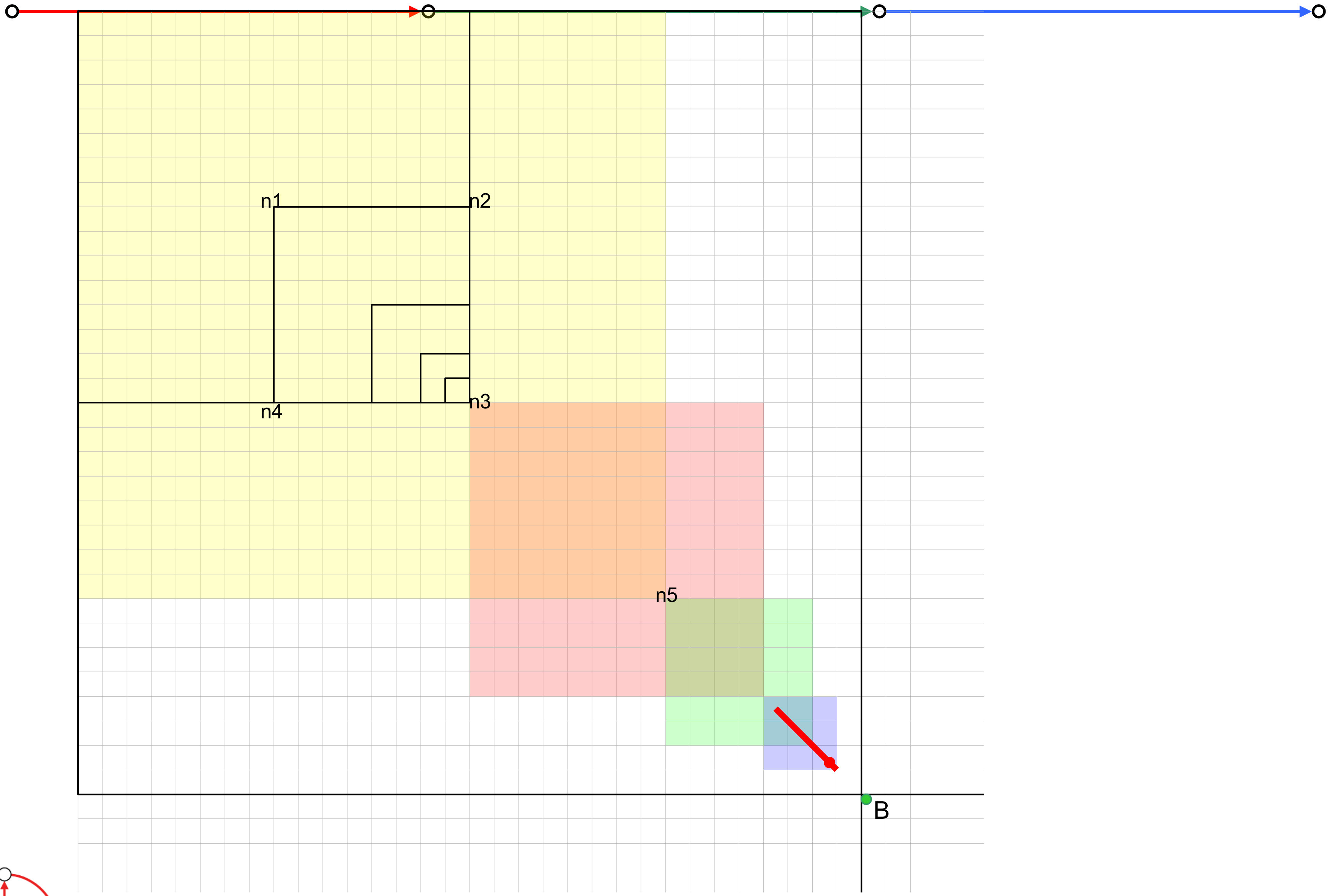

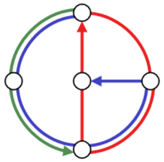

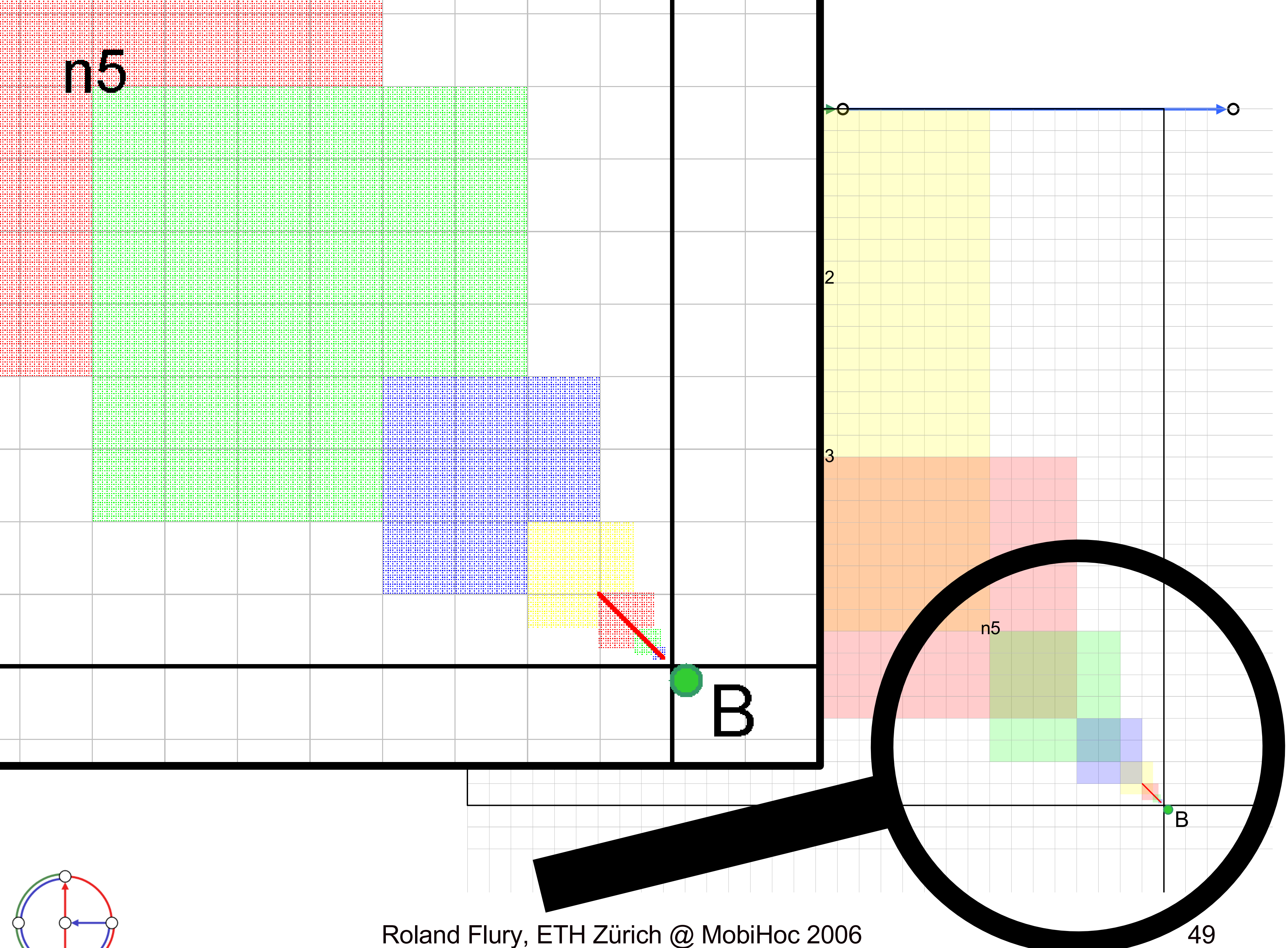
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