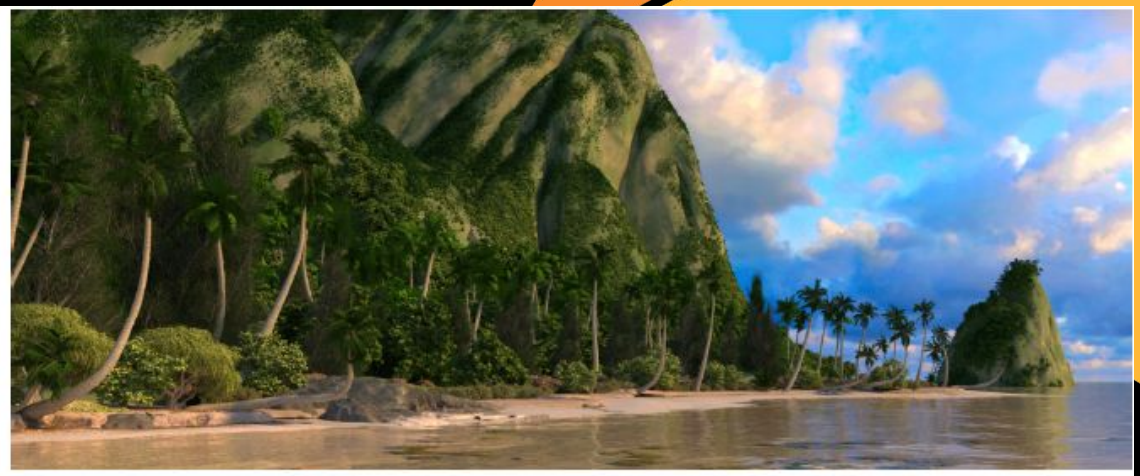
Data Parallel Path Tracing with Object-Hierarchies

Ingo Wald and Steven G Parker

NVIDIA



(Hardware: 4 worker nodes w/ 2×RTX8000, low-end head node, 10-Gigabit Ethernet, screen size 2560 × 1080)

PBRT *landscape*: max 3.7 GB GPU usage, 6.2 FPS (1 path/pixel)
30 K instances, 4.3 B inst. triangles, 370 unique meshes, 500 MB image textures

Disney Moana *island*: max 25 GB GPU usage, 7.9 FPS (1 path/pixel)
39 M instances, 41 B inst. triangles, 7 M unique meshes, 804 MB baked-PTex txt.

About

- Goal: interactive, data-parallel, GPU-enabled, path traced… for Moana-like content
  - Model larger than any one GPU
  - “Production” content
  - Full path tracing

About

- Paper actually about *three different* things
  1) A *new paradigm* re how to think about partitioning and distributed model content
     - More general: different nodes' content can overlap others, etc
  2) A set of algorithms that realize that
  3) A "system" built on these idea & algorithms
     - interactive, wavefront path tracer, GPU, MPI, …

About

Focus of this talk

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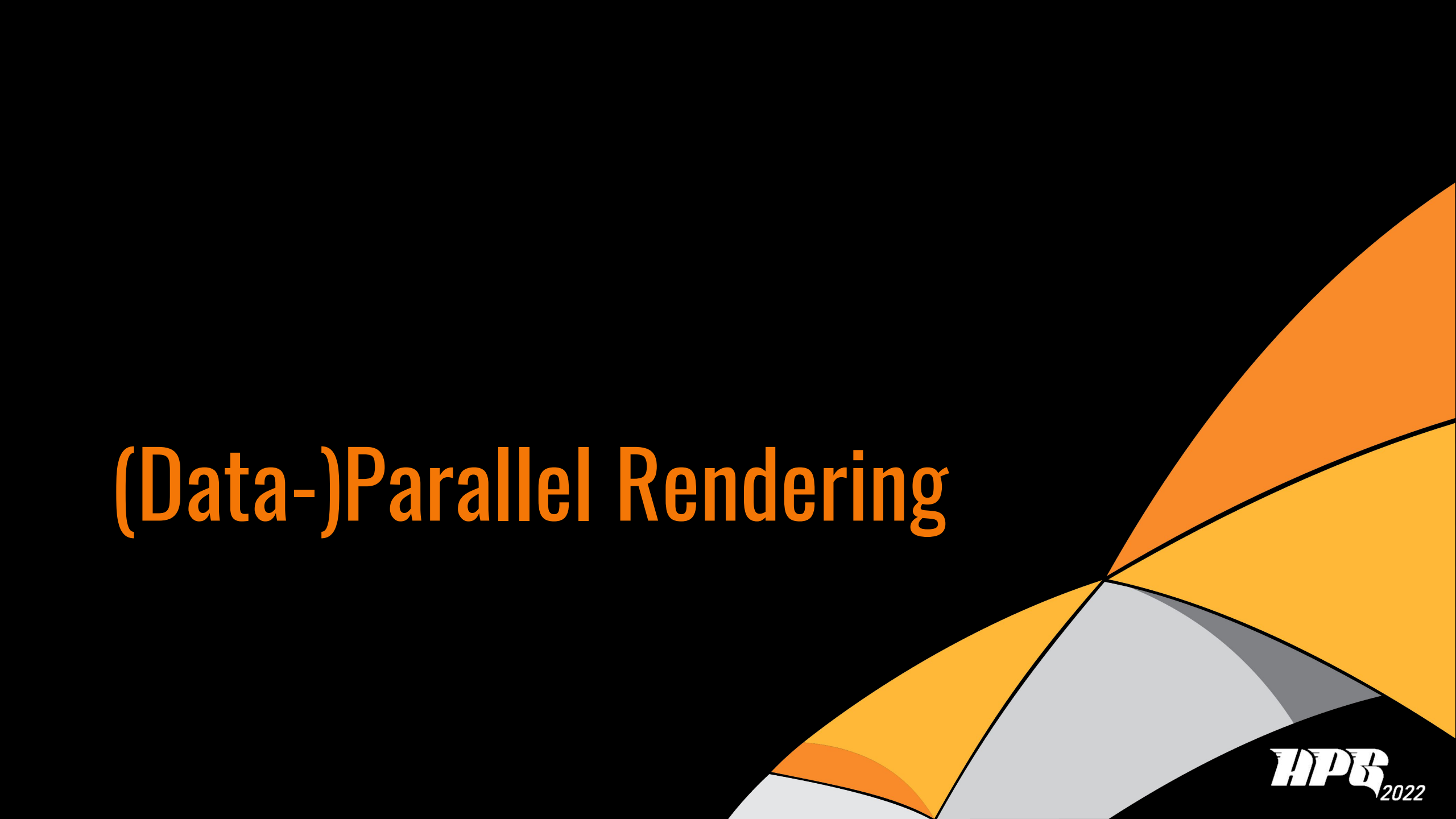
(Data-)Parallel Rendering



(Data-)Parallel Rendering : How ?

- Data-parallel rendering: mult.nodes work together
  - Every node has only part of the model
    - Usually, because model is too big to fit on a single node/GPU

(Data-)Parallel Rendering : How ?

- Data-parallel rendering: mult.nodes work together
- Most used today: “sort-last” image compositing
  - But: doesn’t work for secondary rays not for us

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- When tracing arbitrary rays, and ray needs content that’s on a remote node … two options:
  - Either: fetch model/bvh data to node the ray is on
  - Or: Send (“forward”) ray to the node that has the data

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This talk (see paper for discussion

DPR for Ray Tracing

- Ray forwarding Two key questions:
  - How to partition the scene
  - What nodes should a given ray traverse (and in what order)

- Interesting observations

  a) Not much work on that
    - Some in early times, very little recently

  b) Virtually all prev work assumes spatial partitioning

Ray Forwarding w/ Spatial Partitioning

- Partition scene via octree, grid, k-d tree, etc.
- Easy; results in non-overlapping “domains” (one/rank)

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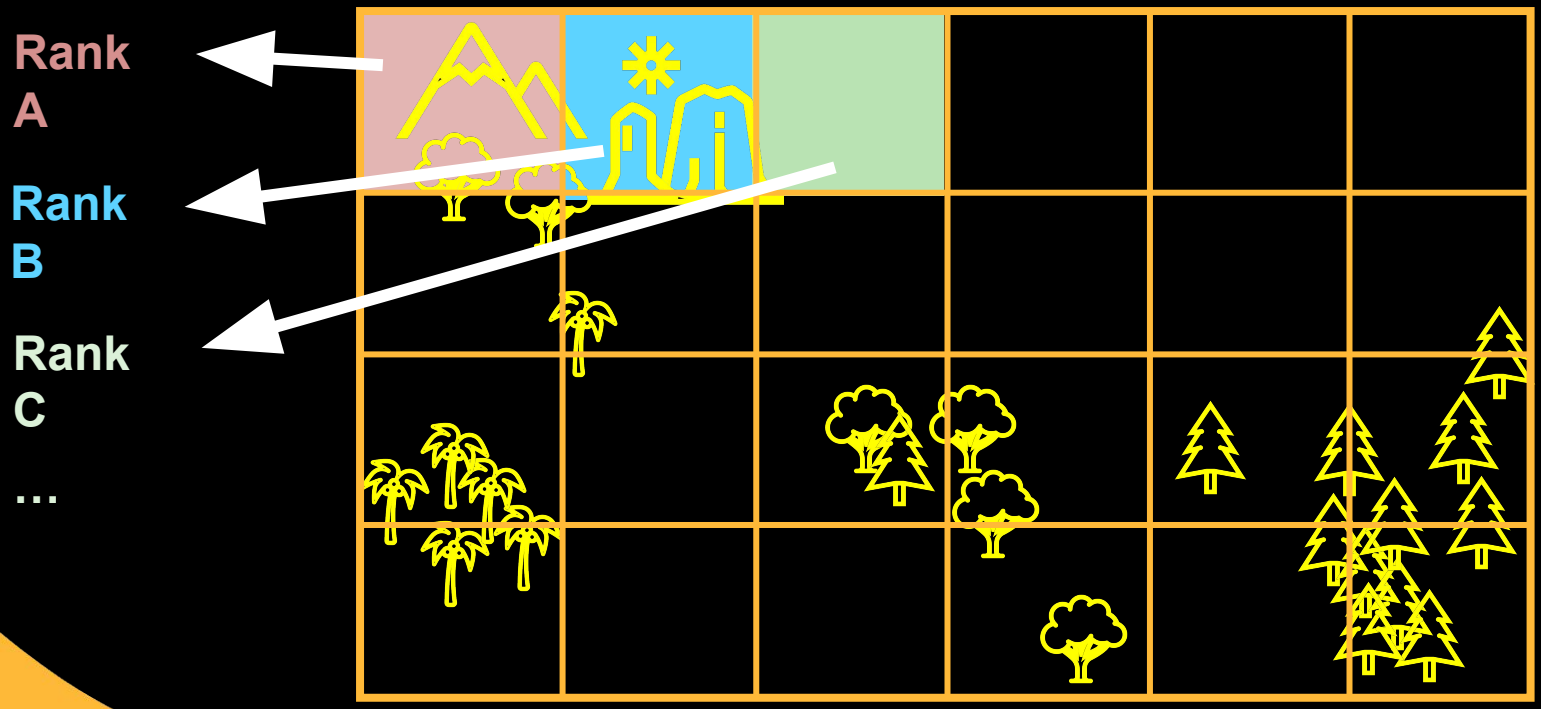
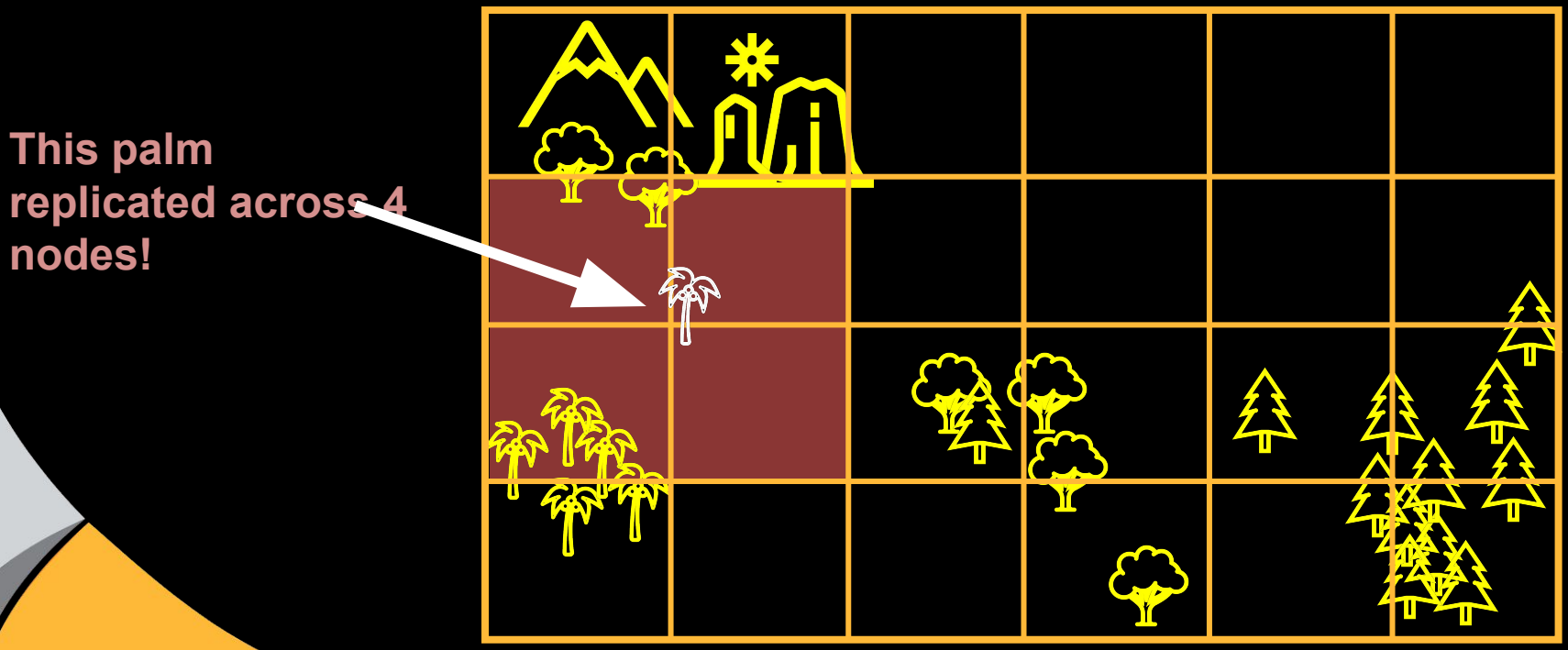


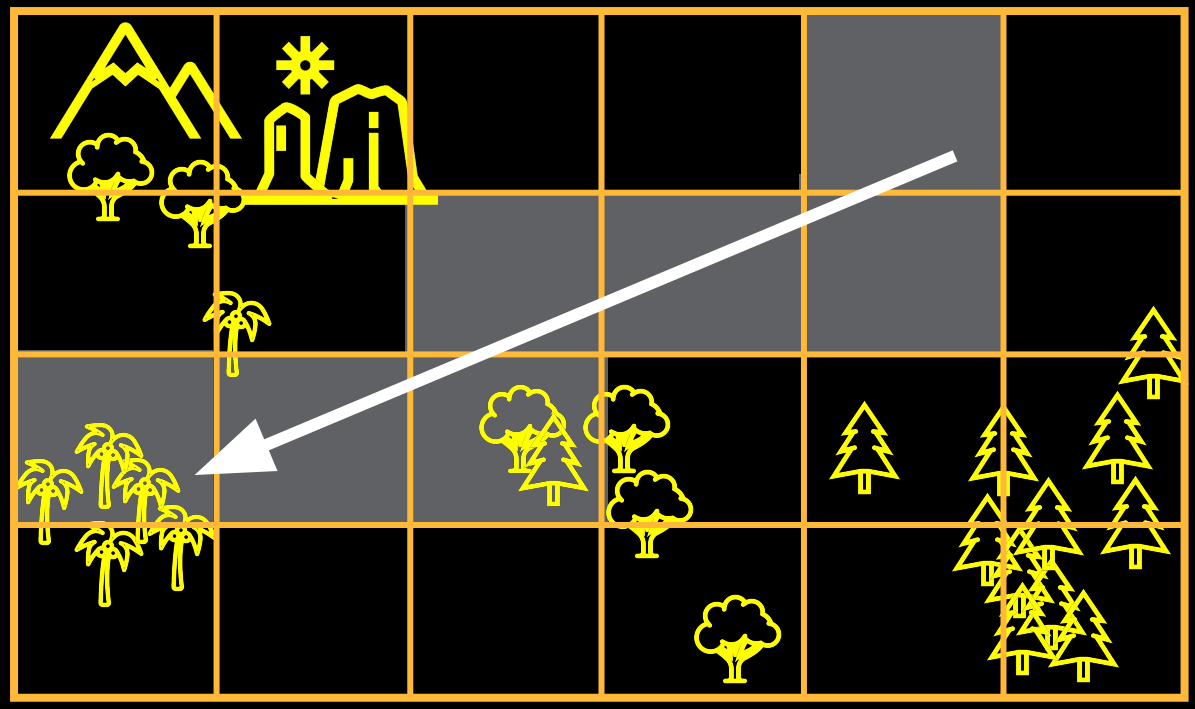
Ray Forwarding w/ Spatial Partitioning

- Partition scene via octree, grid, k-d tree, etc.
- Easy; results in non-overlapping “domains” (one/rank)
  - Prims overlapping more than one domain get replicated



Ray Forwarding w/ Spatial Partitioning

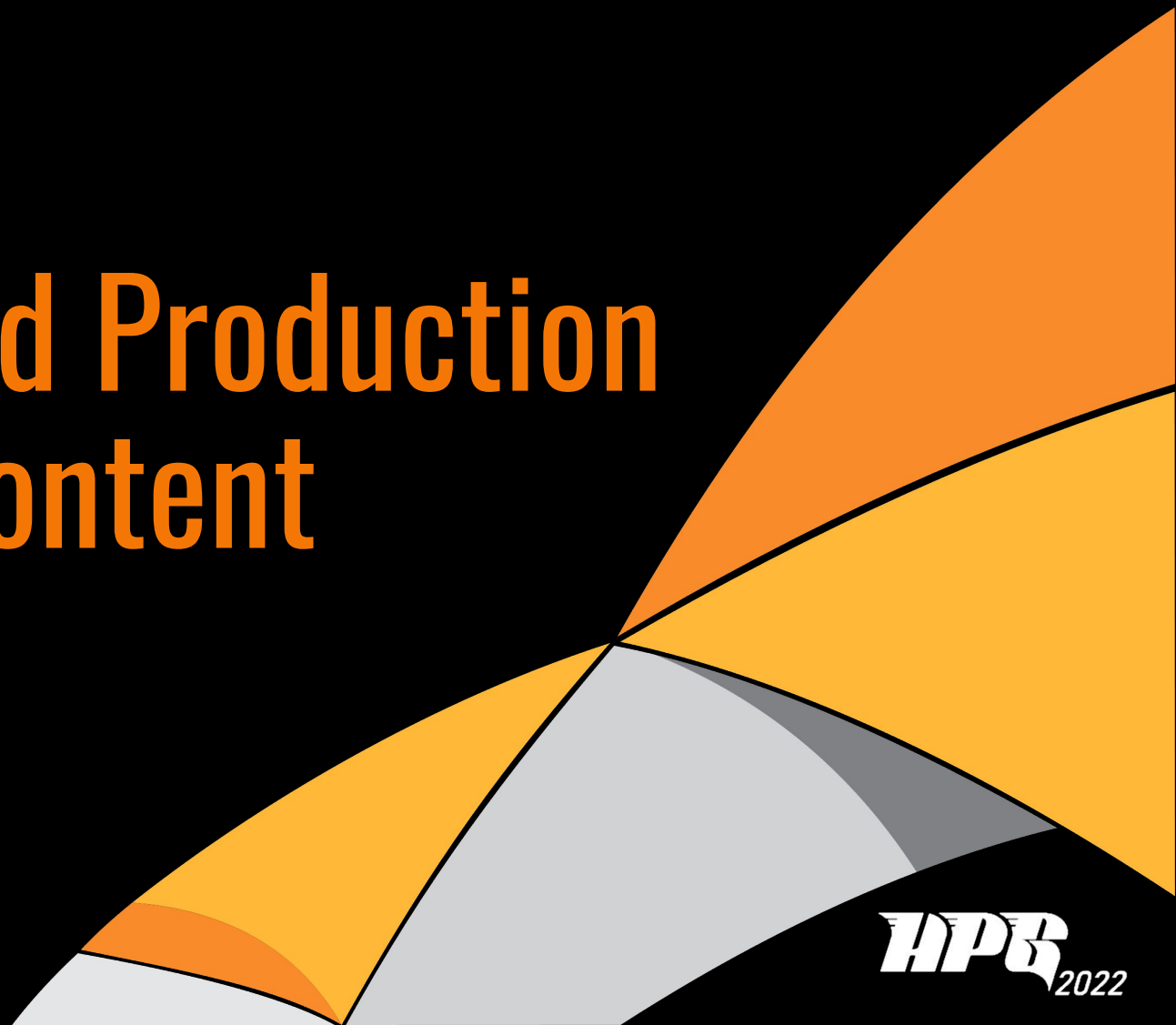
- "Traversing" a ray across ranks is (kind-of) trivial…



Ray Forwarding w/ Spatial Partitioning

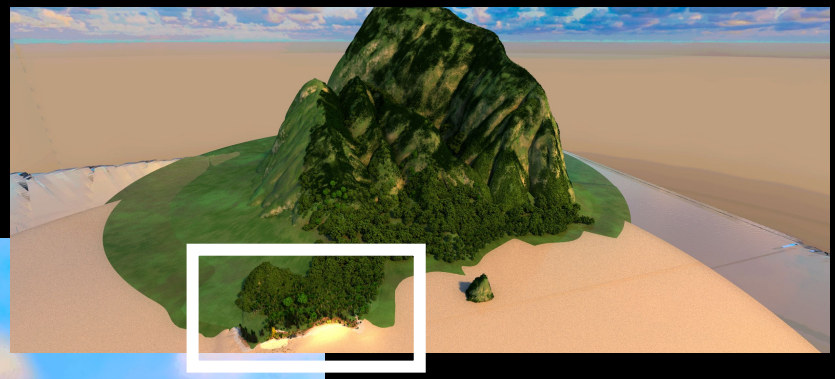
- "Traversing" a ray across ranks is (kind-of) trivial…
- Caveat: "the usual issues" of spatial partitionings
  - Not going into that discussion here …
    - But note: RT has mostly gone from spatial part to object hier.!
  - Main issue: Replication

Ray Forwarding and Production Rendering-Style Content



Production Content: “Moana”

- The actual “shot” view
  - Even top right is only part of whole…



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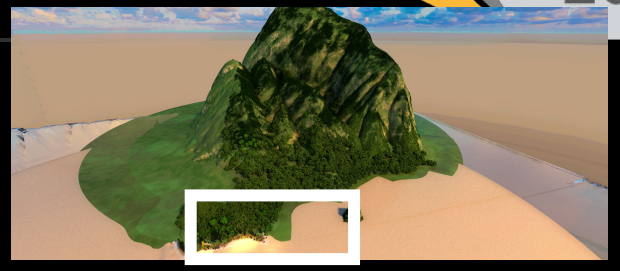


All those twigs, leaves, etc, are all instances

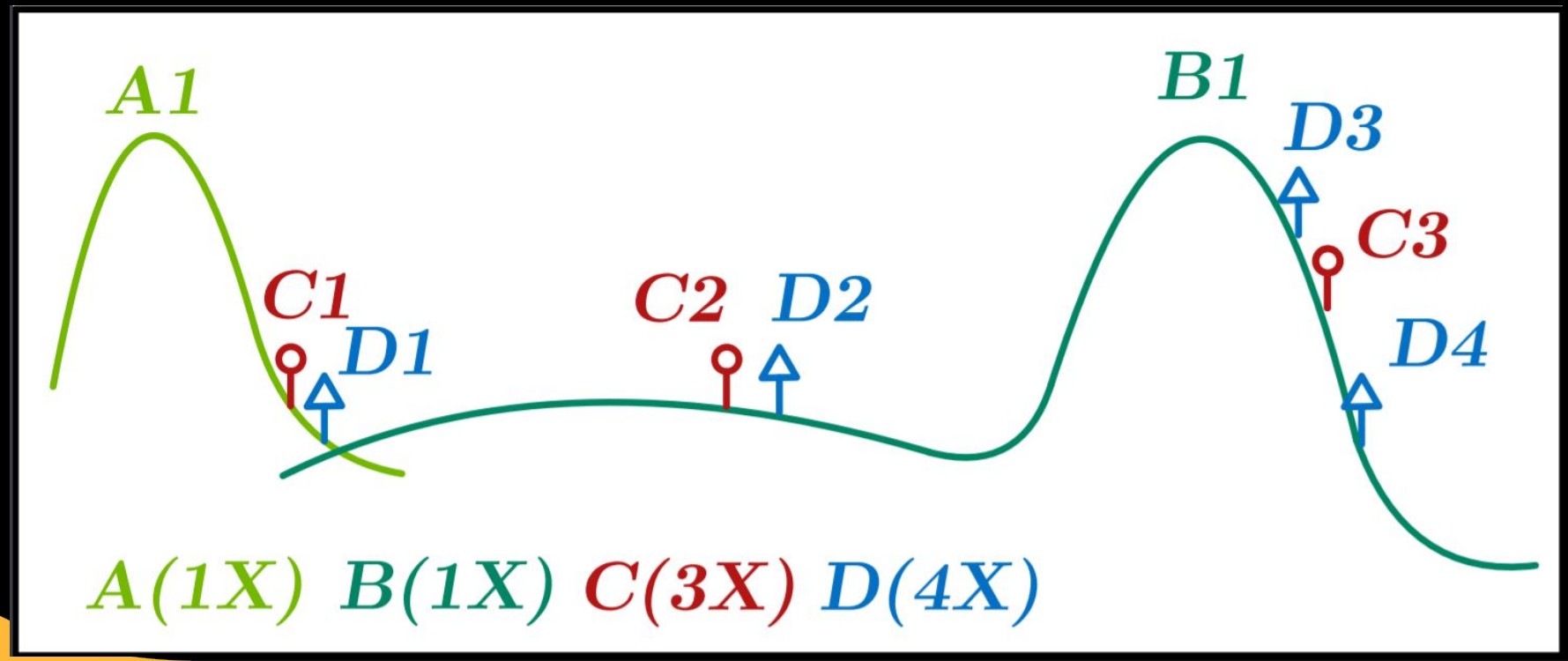
Production Content: “Moana”

- Issues:
  - Some meshes span entire model (or large parts of it)
    - ocean, ocean floor, base of mountain, …
  - Many meshes have instances scattered all over entire model
- Plus: Restrictions on what/how we can split things
  - Instanced Meshes cannot easily be split at all
  - Meshes have shading data (eg: baked textures)

Let’s do a little thought experiment …

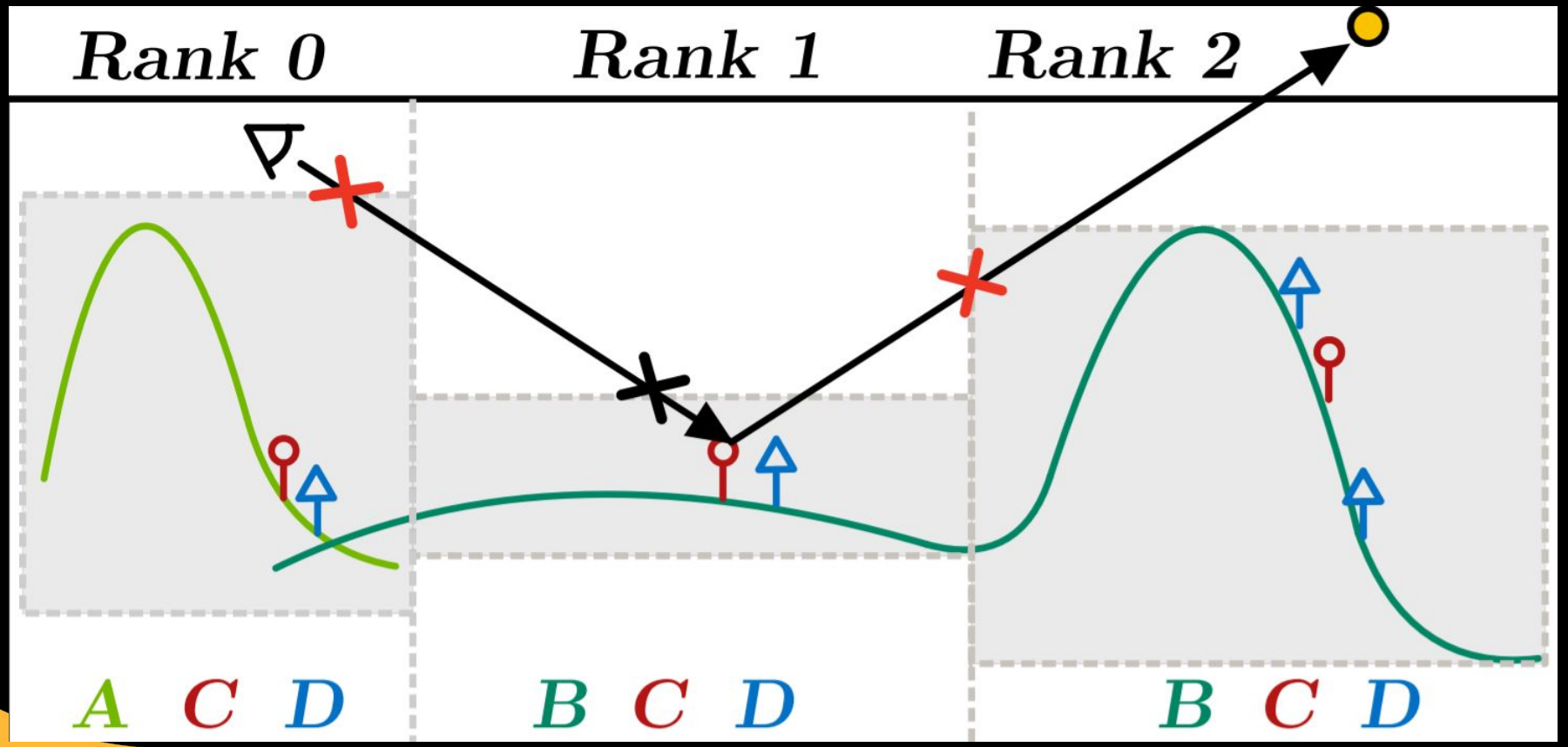
DPRT and Spatial Partition ...

- Consider a “Moana-like” 2D sketch scene
  - One “rock” (A), one “mountain” (B), two types of trees (C,D), several instances of C and D



DPRT and Spatial Partition ...

- Now let's do some (SAH-like?) spatial partitioning and trace some rays simple, trivial to traverse this

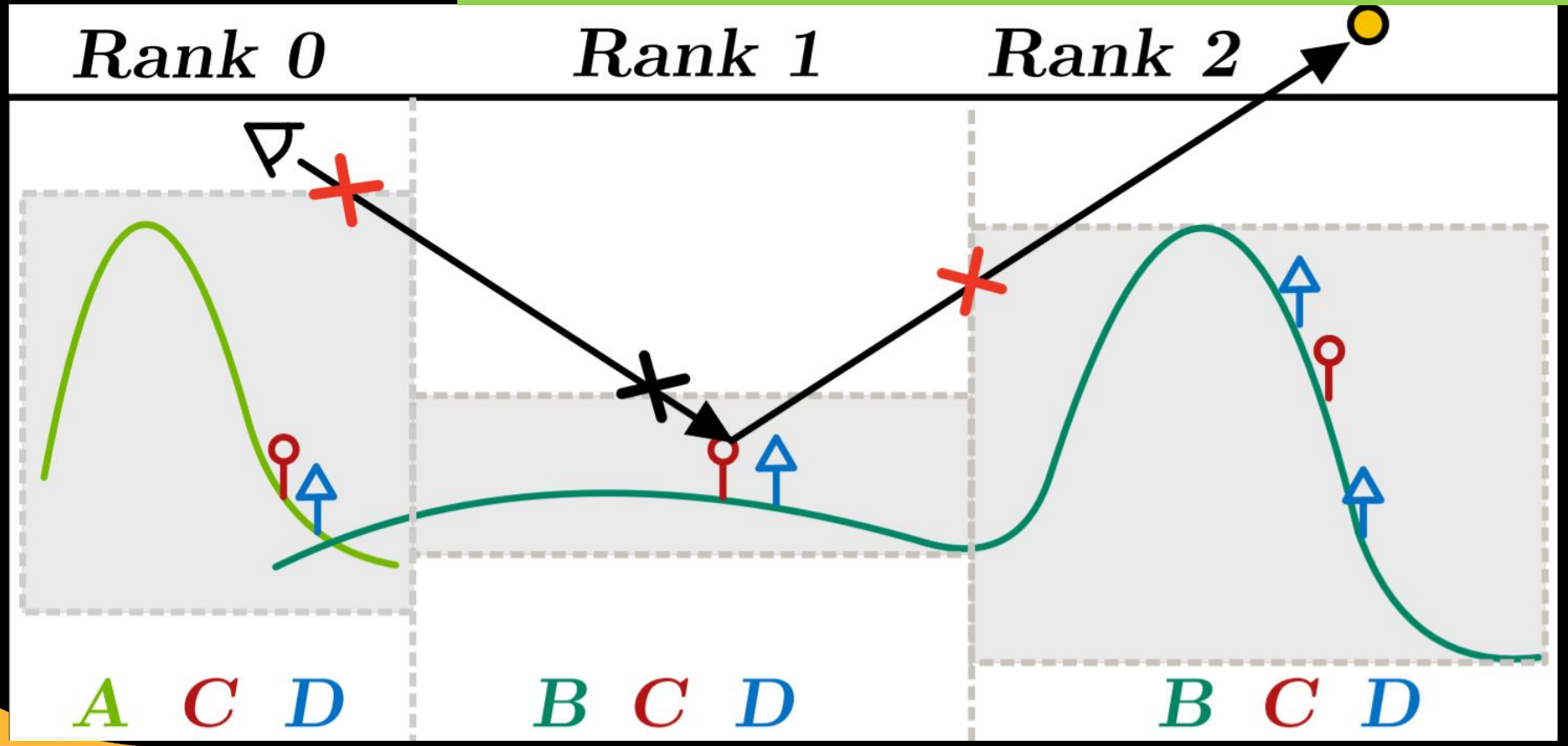


DPRT and Spatial Partition …

- Now let's do some (S
  and trace some rays

BUT: Every rank has (almost) every object!

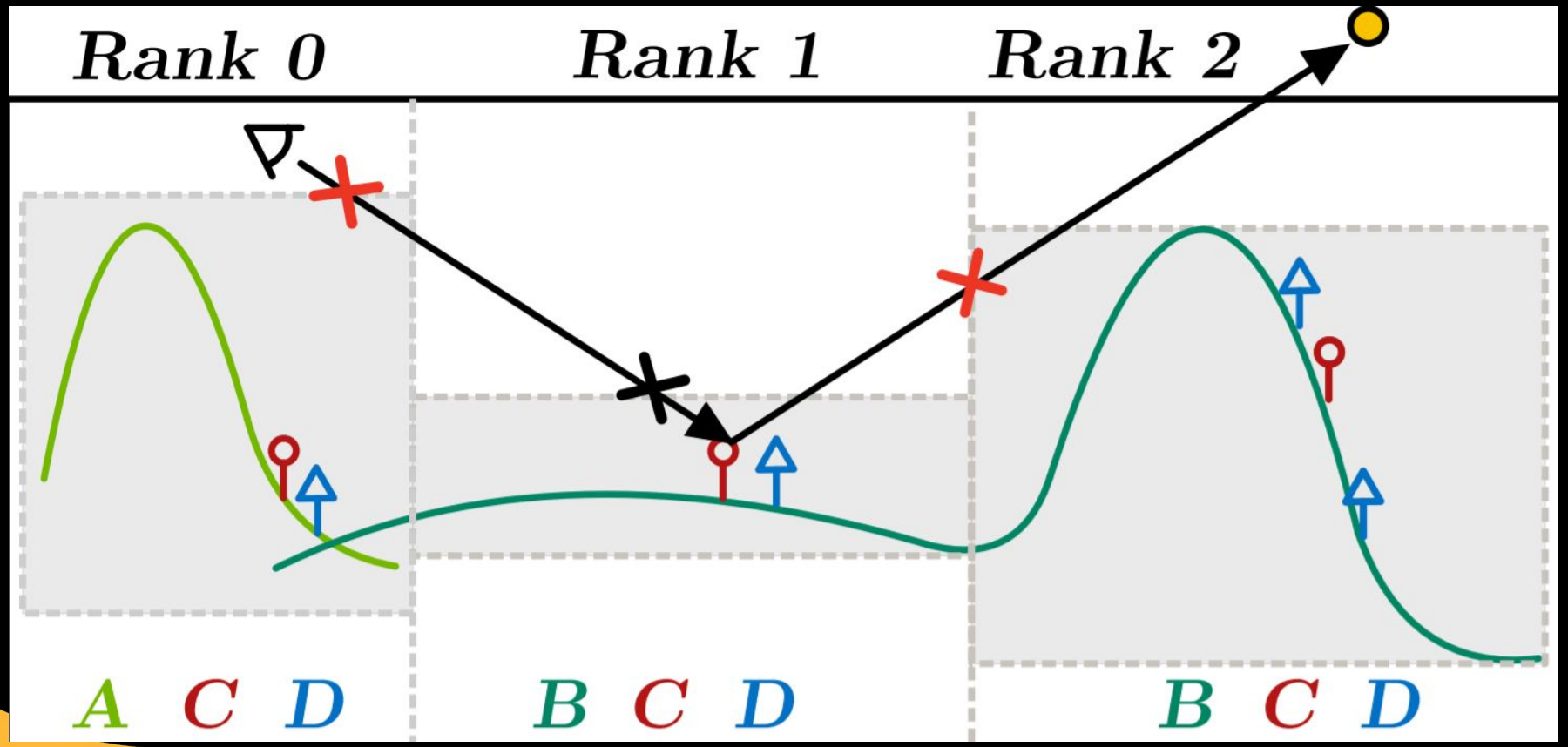
(Note bug in that sketch: R0 actually also has a copy of the green mesh, so has *every* mesh that the un-split model has!)



DPRT and Spatial Partition …

- Now let's do some (SAH-like?) spatial partitioning and trace some ray

Observation 2: both rays touch two ranks even though they're not even close to R0 or R2!



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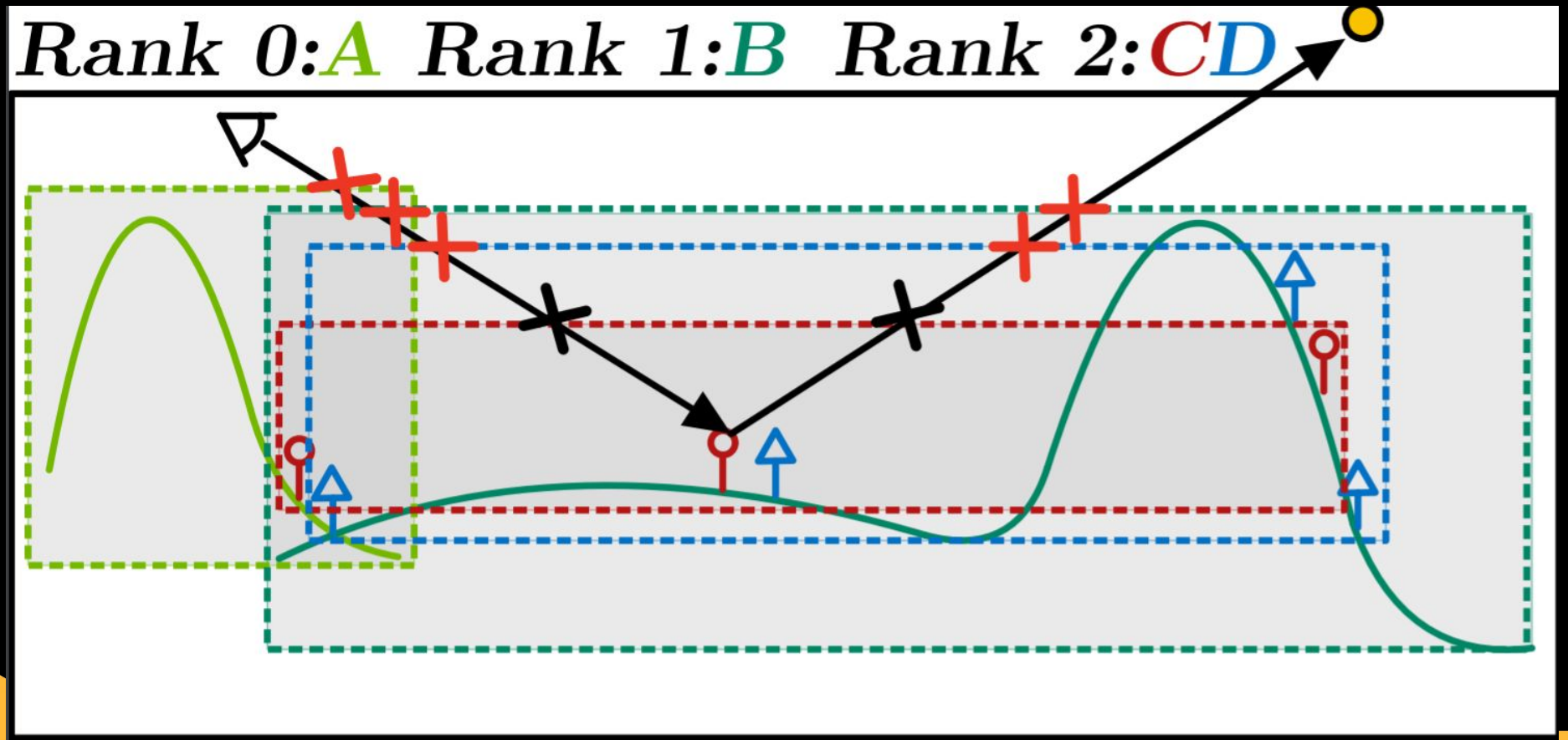
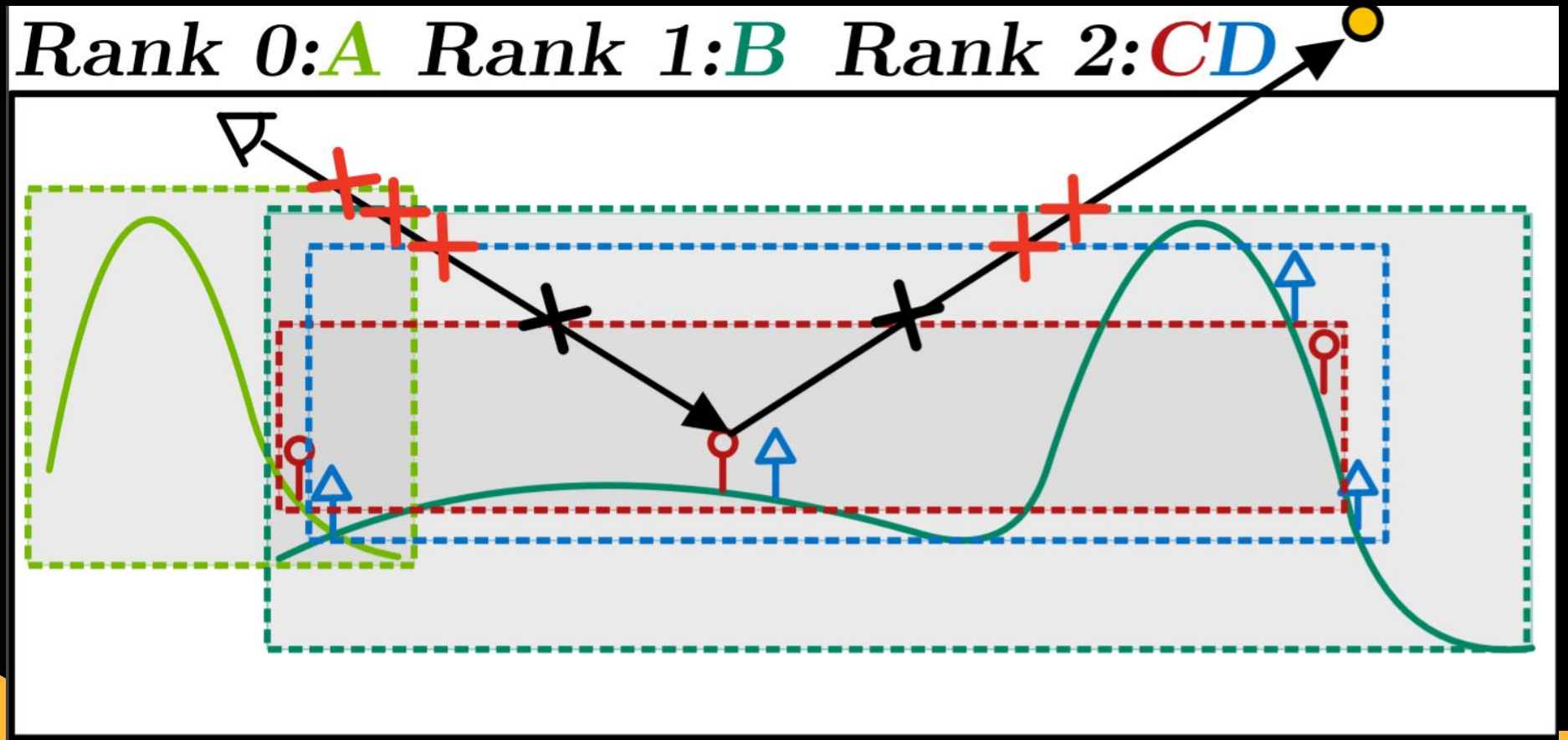
- Partition by object type rather than by space
- Let's put A to rank 0, B to rank 1, and rest to rank 2



So, … What about Obj

- Partition by object type rath
- Let's put A to rank 0, B to rank 1, and rest to rank 2

Much better for partitioning
(▫ every mesh on only one node)
… BUT:
a) How do we even traverse this!?
b) *Really* bad for forwarding: *every ray goes every rank*
(maybe there's a reason nobody ever did that)



Applying spatial splits & re-braiding eqiv.

- Spatial splits & re-braiding: represent large meshes or instances with multiple smaller, tighter boxes

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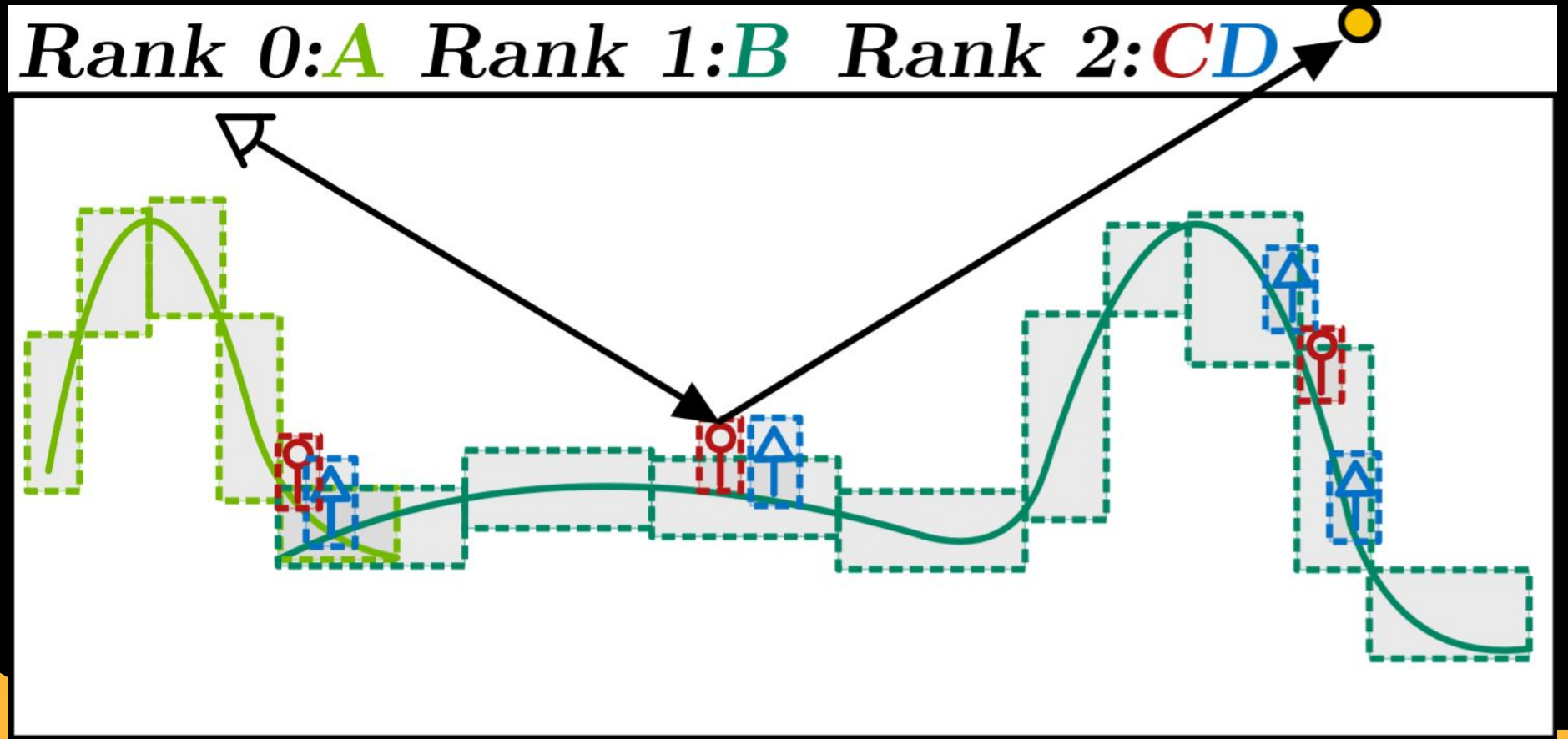

Distributed Ray Traversal w/ Object-space Hierarchies

Distr. Ray Traversal in Object Space

- Key idea, Part 1: More general description of distributed content via “proxies”
  - Proxy = region of space describing remote content
- Every proxy has
  - a) 3-D world-space bounding box (region of space)
  - b) List of node(s) that own data behind that box

Proxies

- Naïve: one proxy / inst, each inst on one rank

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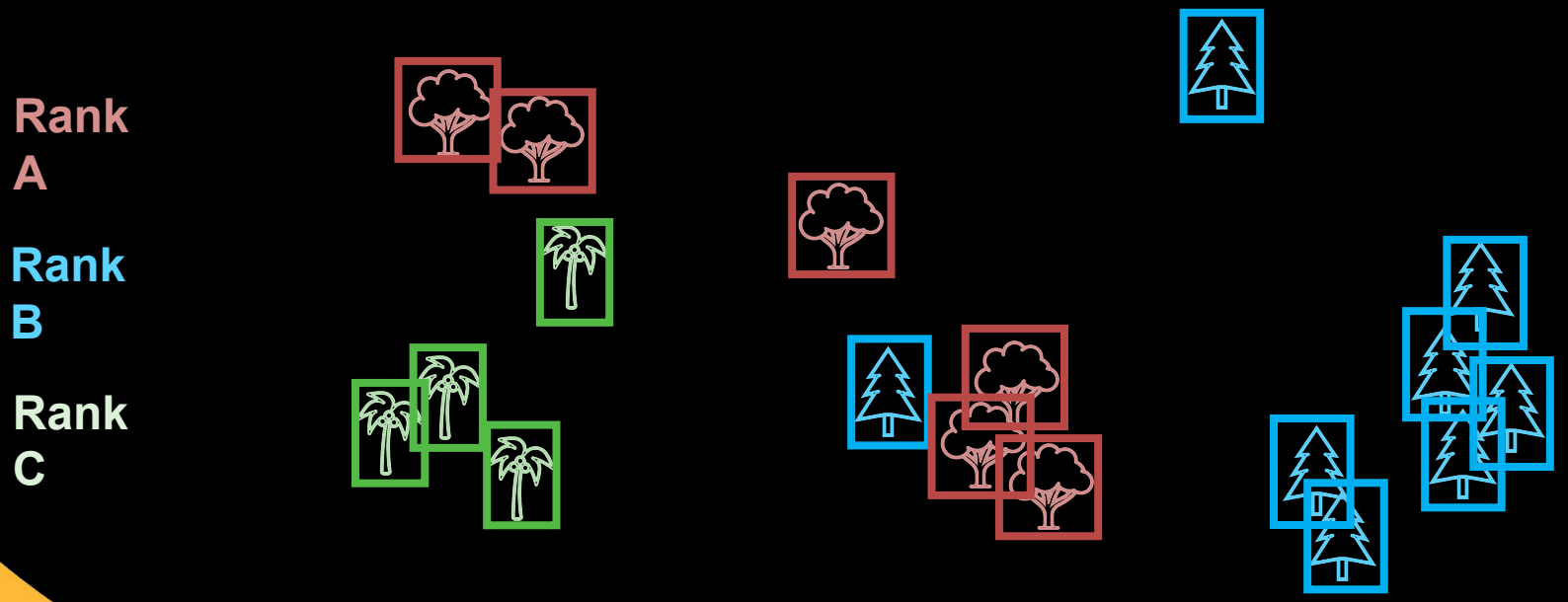

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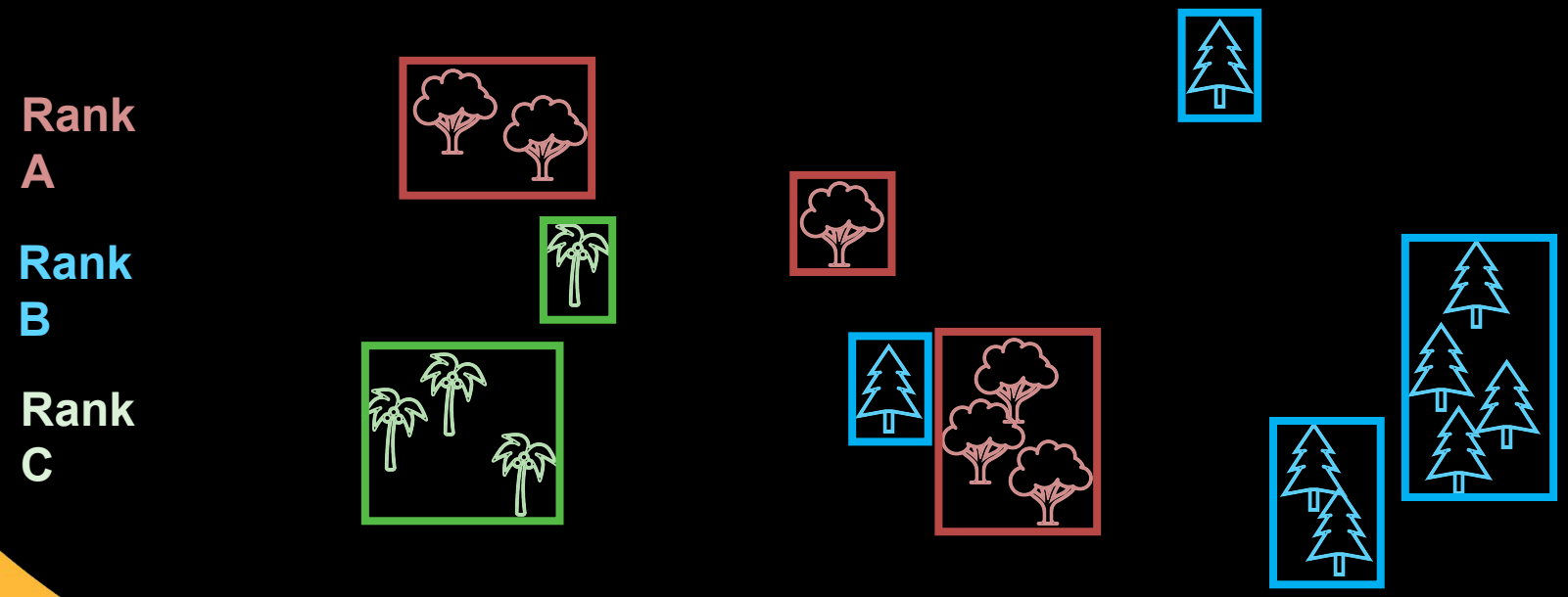

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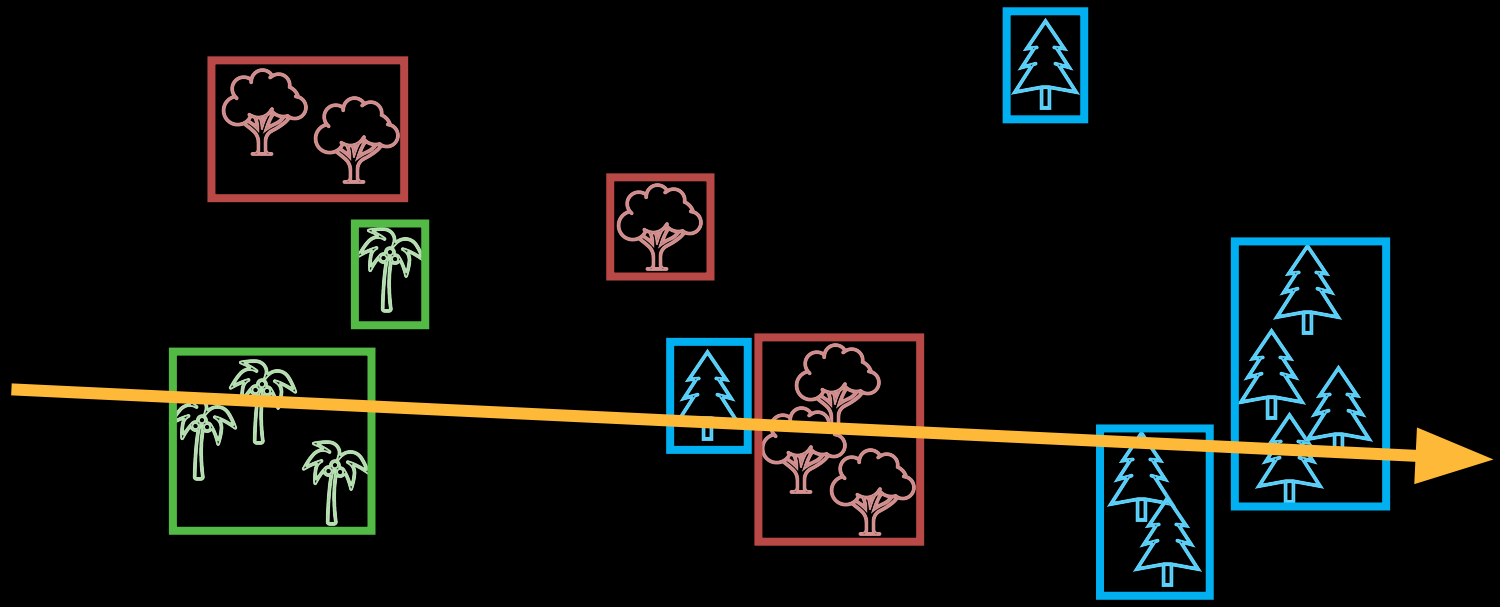
Distributed Ray Traversal

- First idea: traverse from proxy to proxy (stack-free?)



Distributed Ray Traversal

- First idea: traverse from proxy to proxy (stack-free?)

- But: *Lots* of issues with this …
  - Stability (not going into that here)
  - Possibly *tons* of proxies along a ray
  - Rays can actually go back-and-forth between same node(s)

Distributed Ray Traversal

- Better: always get next “not yet travrsed node” proxy
  - Build BVH over proxies
  - Have each ray track which nodes it’s already been on
  - Trace ray into proxy BVH, skip all proxies for nodes ray has already been one… find closest it hasn’t been on!

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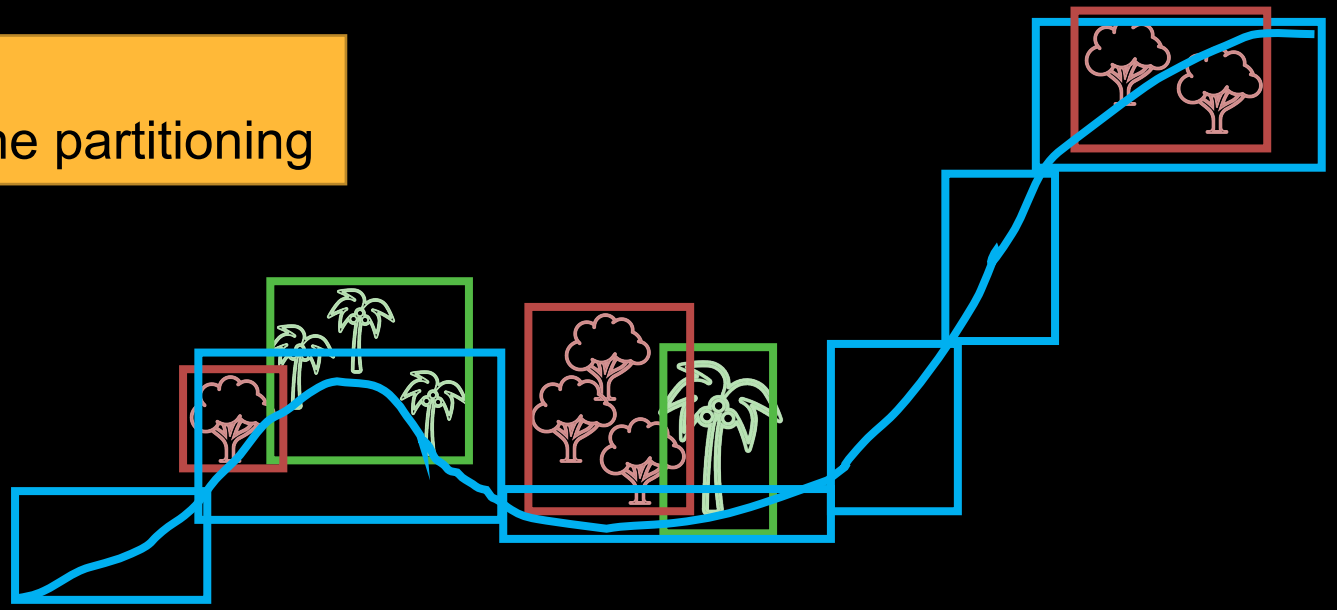
- Take this scene partitioning



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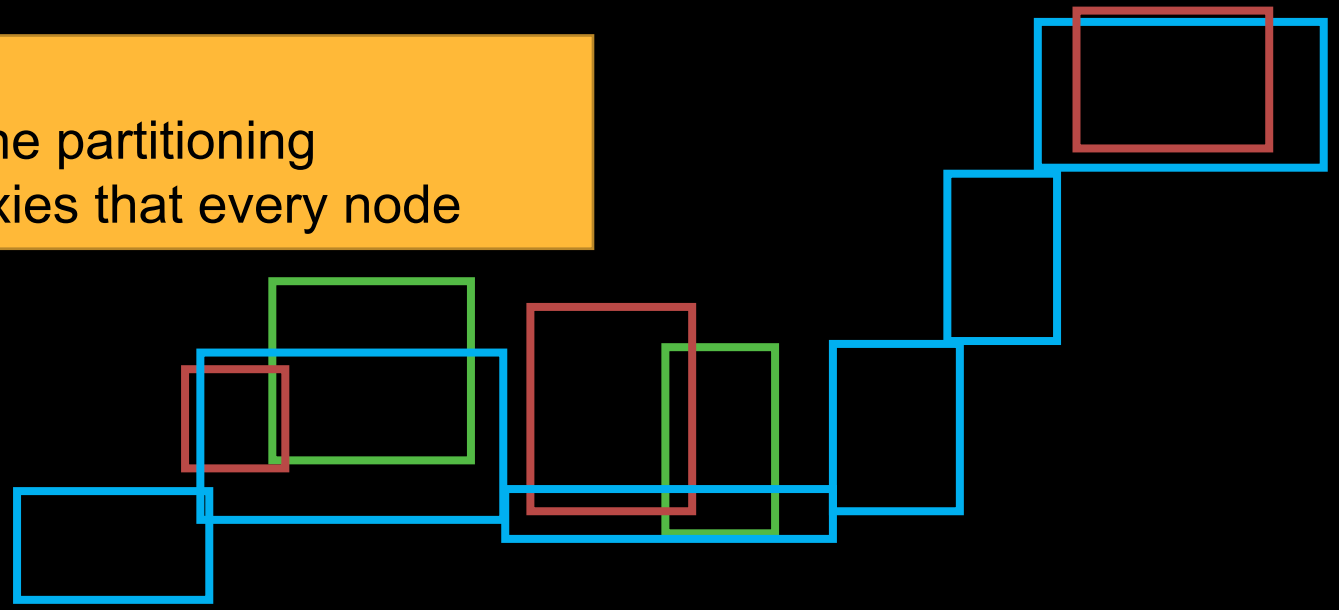

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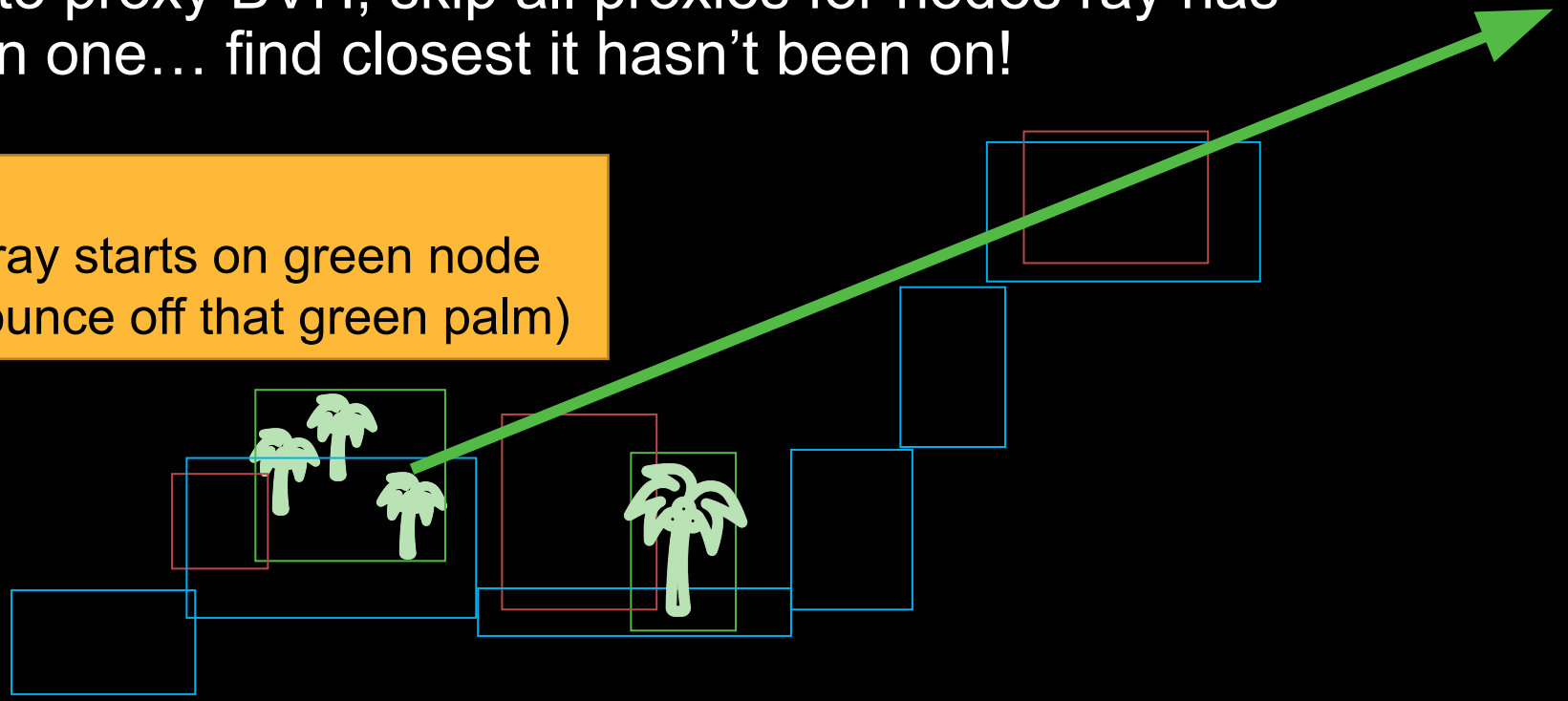
Example:
- Assume new ray starts on green node (eg, diffuse bounce off that green palm)



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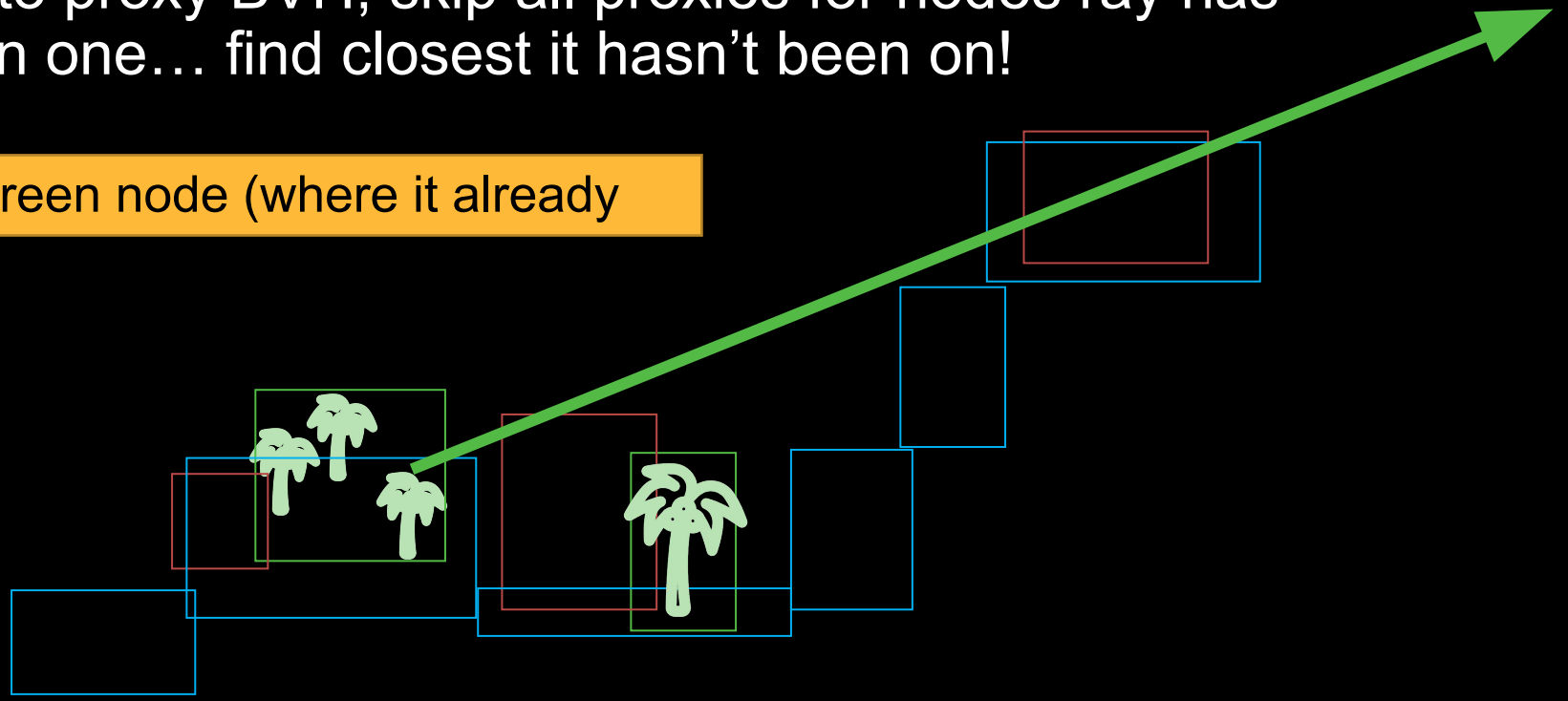
1) Trace ray on green node (where it already



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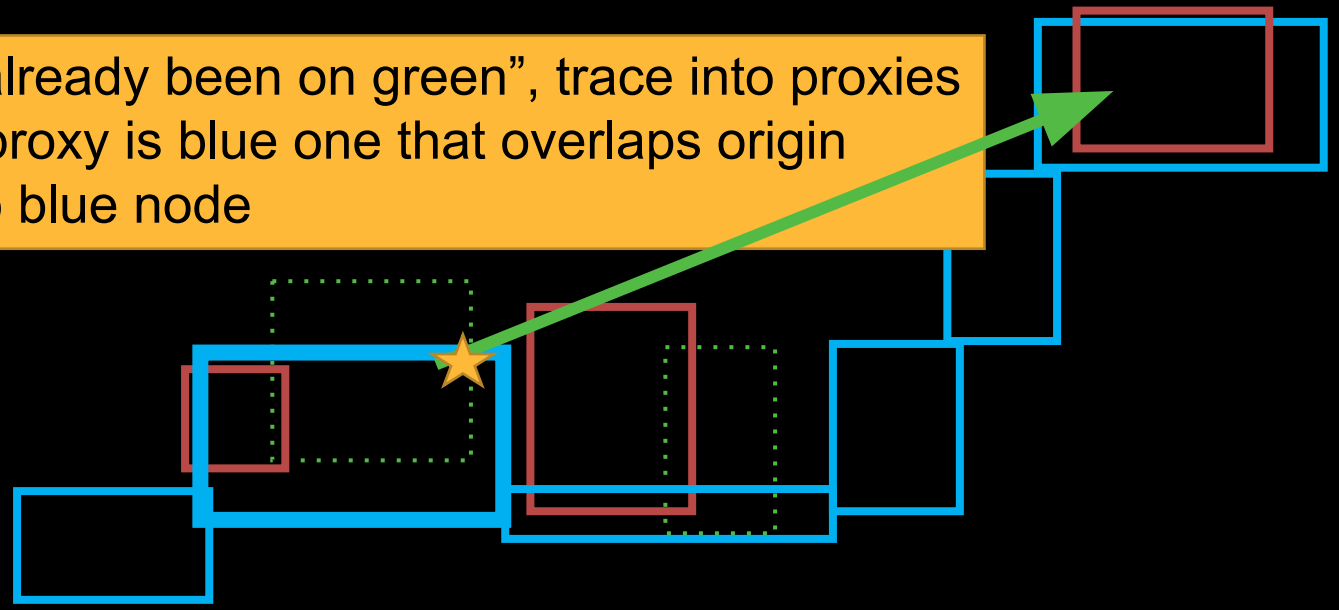
2) Mark ray as “already been on green”, trace into proxies
- Closest “live” proxy is blue one that overlaps origin
- Needs to go to blue node



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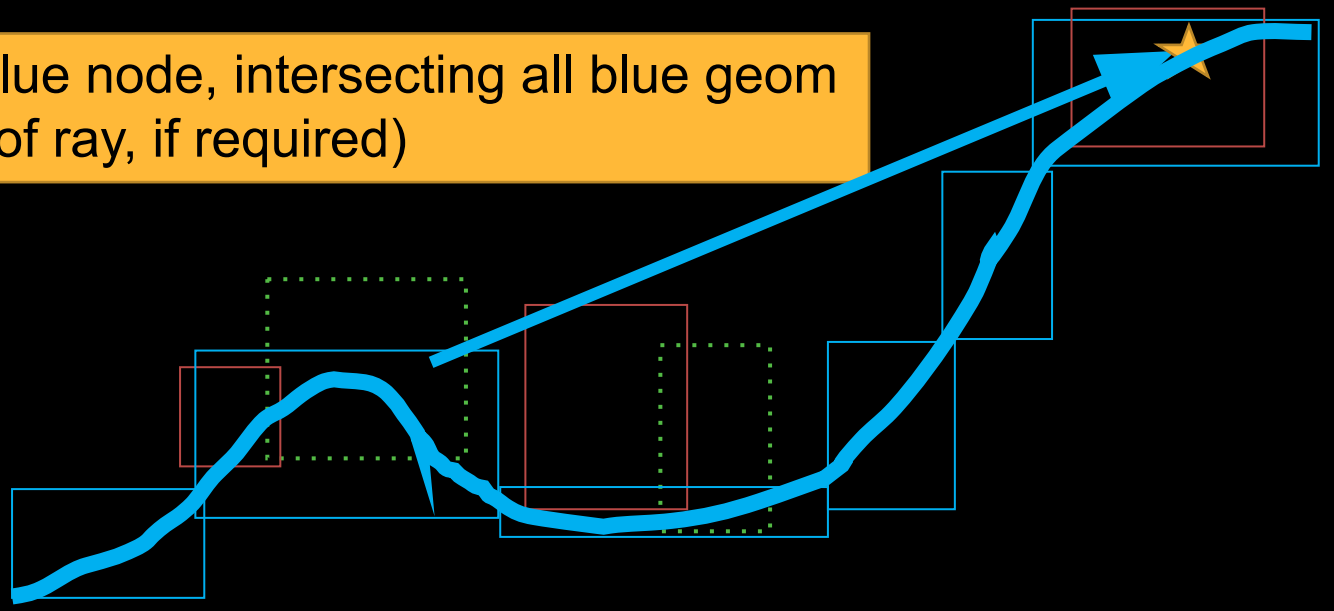
3) Trace ray on blue node, intersecting all blue geom (update hit point of ray, if required)



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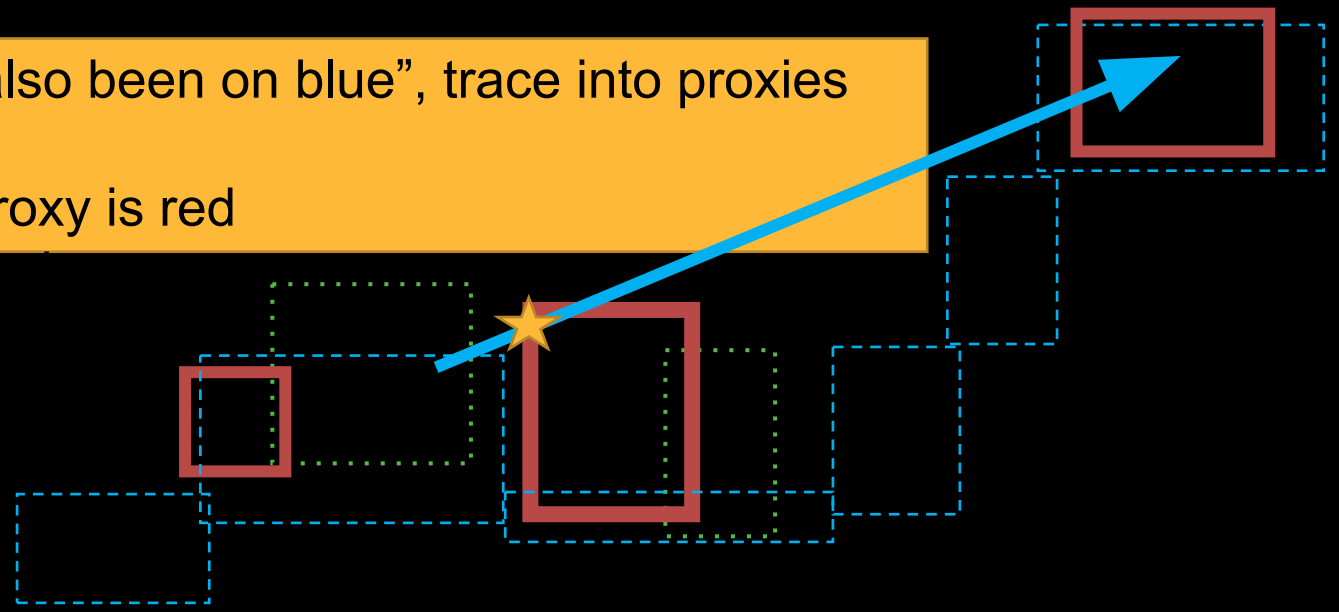
4) Mark ray as “also been on blue”, trace into proxies

…

 Closest live proxy is red



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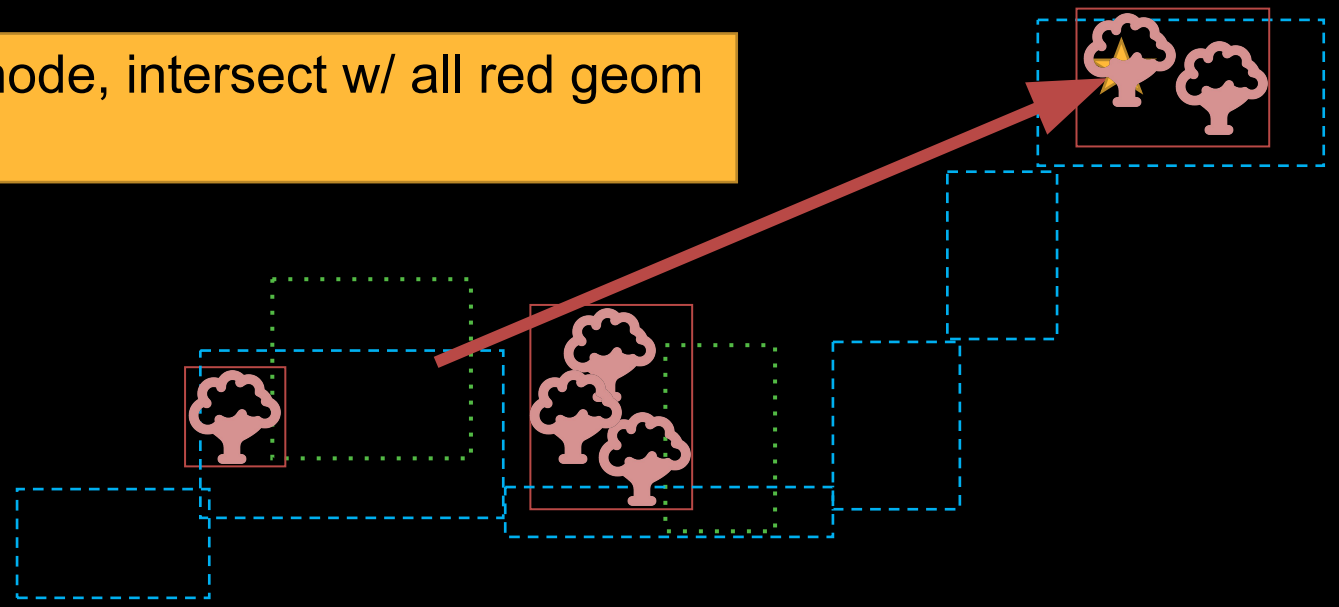
5) Trace on red node, intersect w/ all red geom (update hit point)



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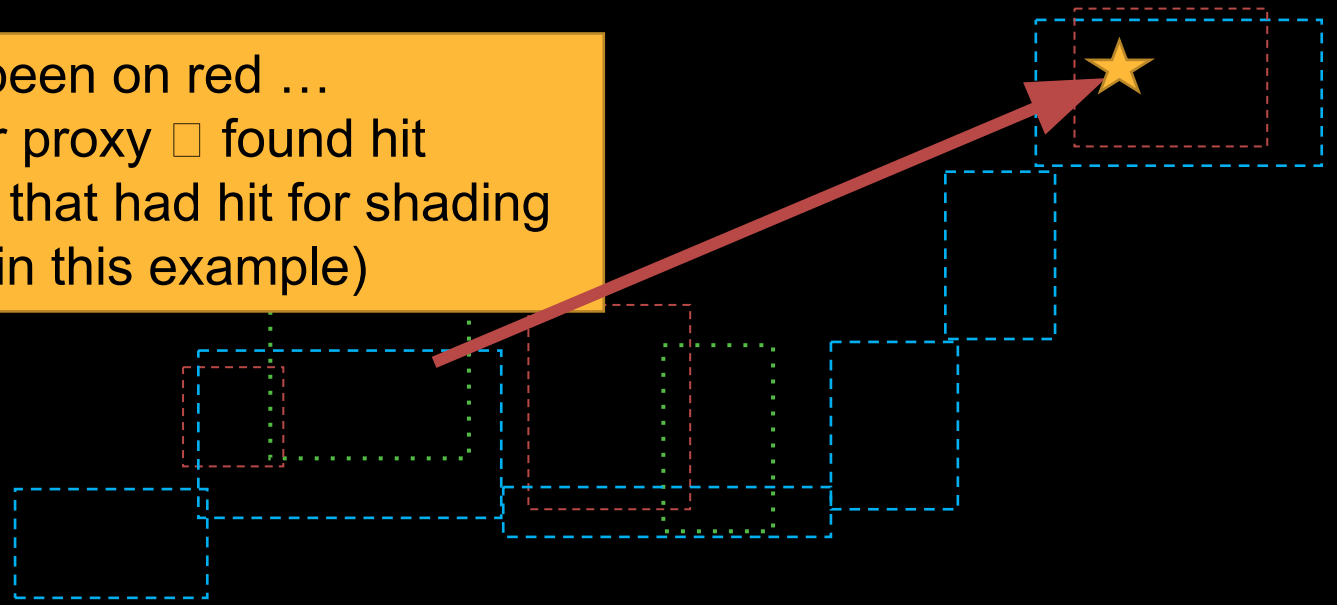
6) Mark as also been on red …
 no other closer proxy found hit
  Move to node that had hit for shading (already on it in this example)



Paper: Putting that idea in practice …

- How to …
  - …do the actual scene partitioning
  - …track previously visited nodes
  - … build a full system w/ that
  - …
- No details here – see the paper …

Results (Teaser)

- Object-space splits way better for partitioning
  - Generally (way) less data per node (no repl, duh!)

  - Can reach same memory budget w/ less splits/nodes!
    - Cheaper *and* faster
  - Spatial often can't get below certain budget *at all*

  - And way more *general* where content can be

Results (Teaser)

- Object-space splits way better for partitioning
- With good partitioning, also *faster* than spatial
  - Tight proxies = little forwarding = faster

Results (Teaser)

- Object-space splits way better for partitioning
- With good partitioning, also *faster* than spatial
- Proxies can *also* represent classical spatial partitions
  - Not “either/or”, but super-set of state of the art

Results (Teaser)

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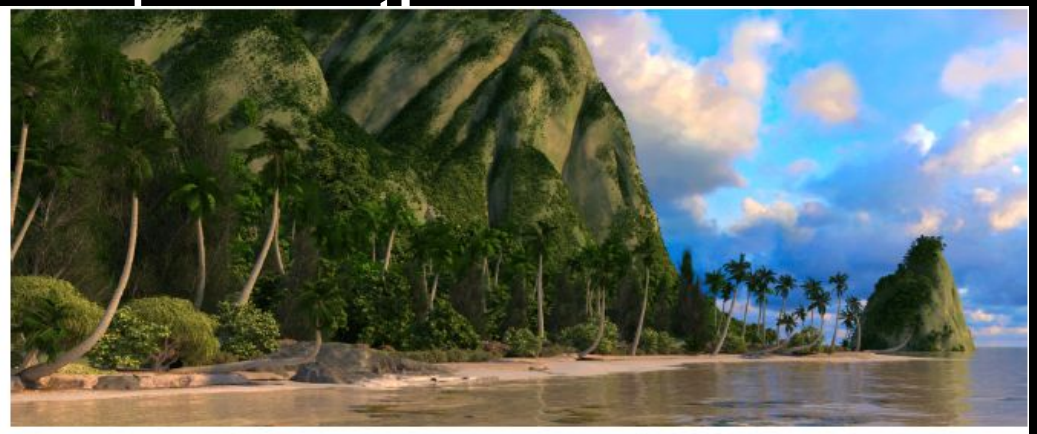

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30 K instances, 4.3 B inst. triangles, 370 unique meshes, 500 MB image textures	39 M instances, 41 B inst. triangles, 7 M unique meshes, 804 MB baked-PTex txt.

The End …

- Many details I glossed over □ paper
- Some remaining issues not solved yet … □ paper
- Questions?

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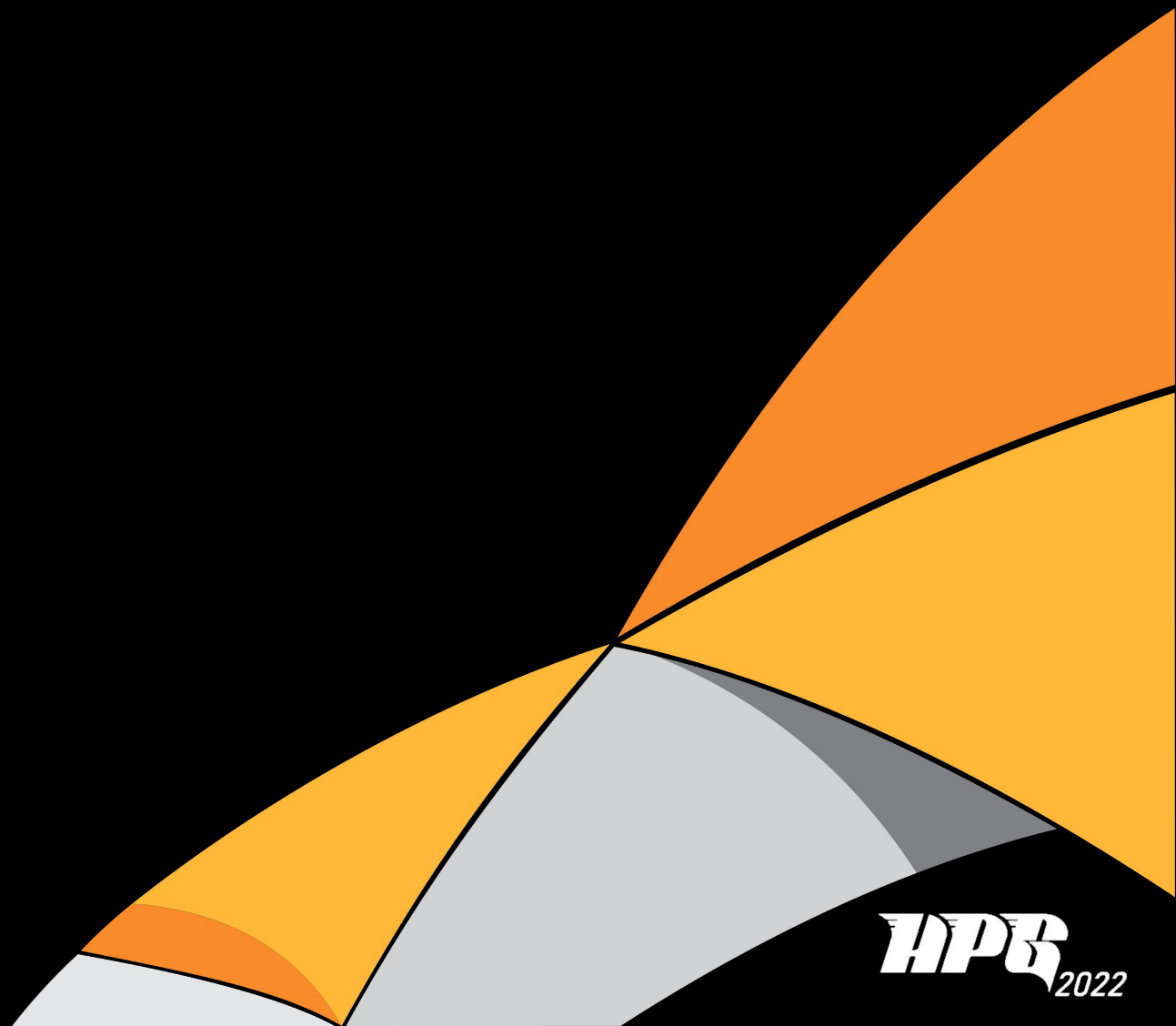
Out-takes



Proxies

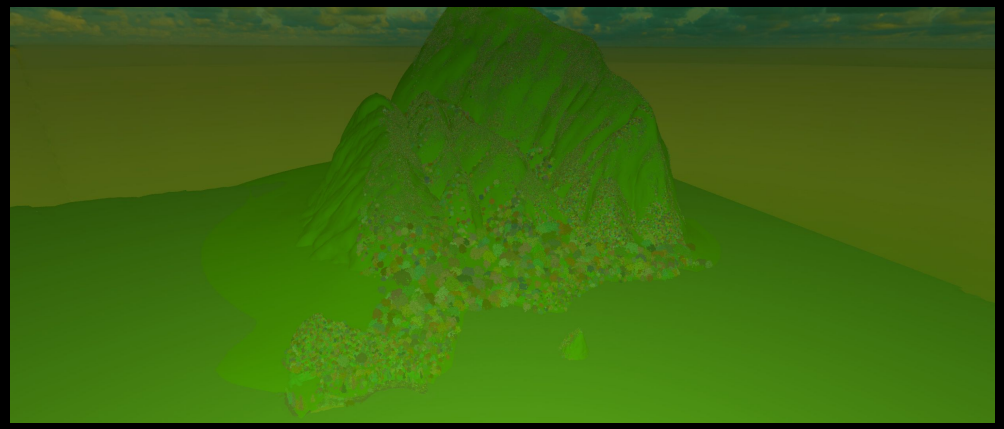
- Naïve: one proxy / inst, each inst on one rank
  - But: could also have more than one inst in a proxy…
  - … or more than one proxy per any geom…
  - … or even replicate some insts to more than one rank
- Eventually: *Very* general
  - 3D box that contains “something”…
    - A mesh, an instance, part of a mesh or instance, …. *something*
  - … and that something is available on any of the listed node(s)

Paper: Putting that idea in practice …

- How to do the actual scene partitioning
  - Several options in the paper (incl one “good” one)
  - But: Certainly not fully solved problem yet
    - Surprisingly tricky problem …
    - Anybody looking for a challenging graphics problem?
- Build a system with GPUs, OptiX, CUDA, MPI, …
  - Data parallel “closest hit” operator (what we sketched)
  - Wavefront path tracer (on top of that)
- Performance evaluation and discussion

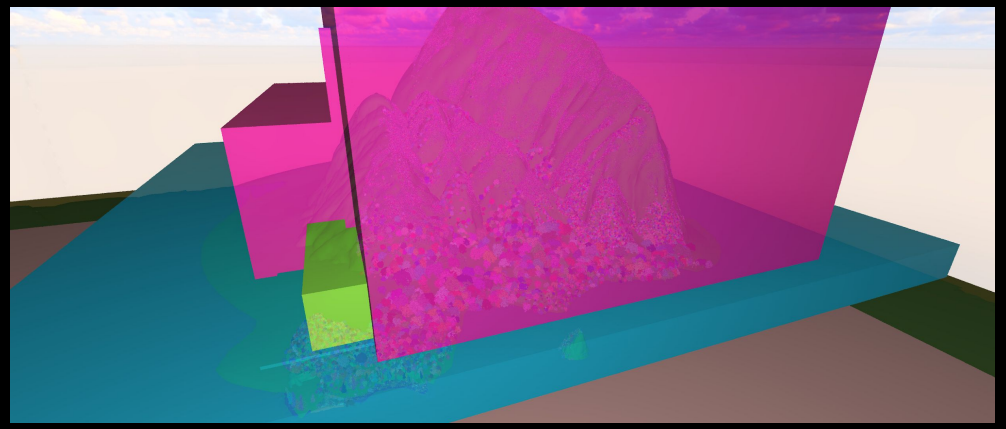
 No time here for details: go read the paper!

Proxies in practice (Moana)



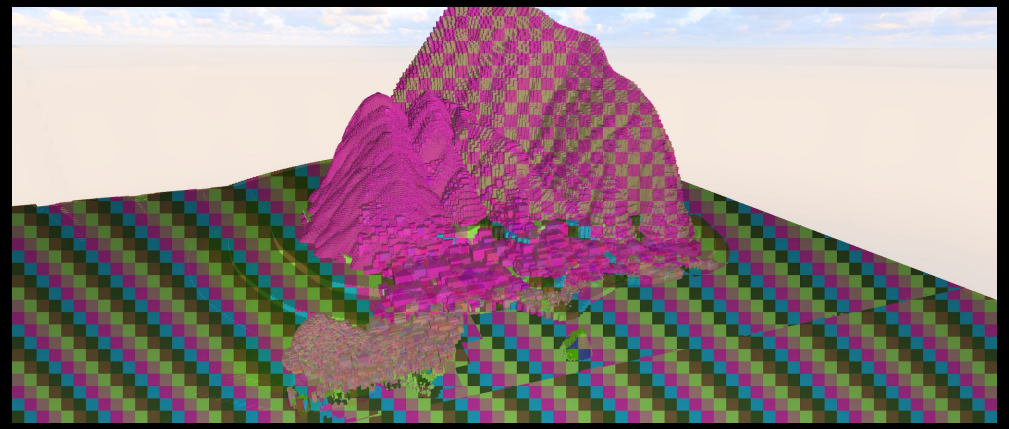
Proxies – spatial only

- domain boxes are *huge:* lots of forwards



Proxies – object hier. naïve

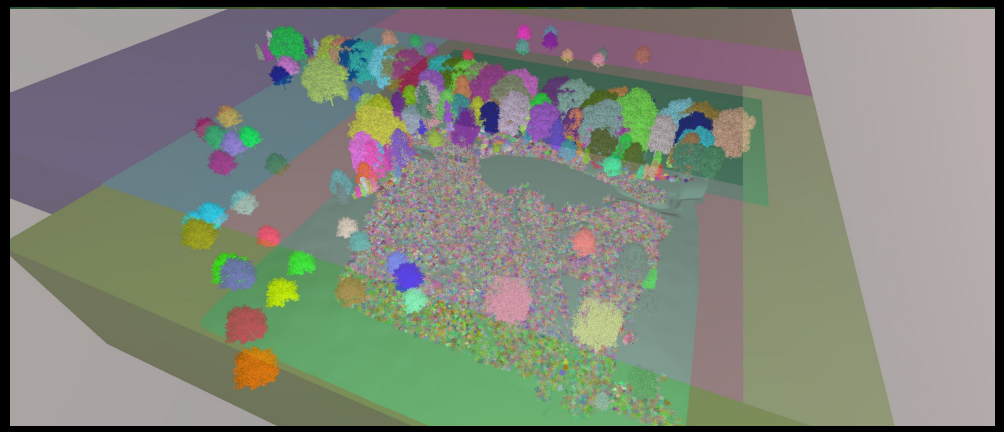
- some proxies still huge: lots of overlap, lots of fwds



Proxies – “best” (striped means “replicated”)

- first proxy is often the correct node already

Proxies in practice (PBRT Landscape)



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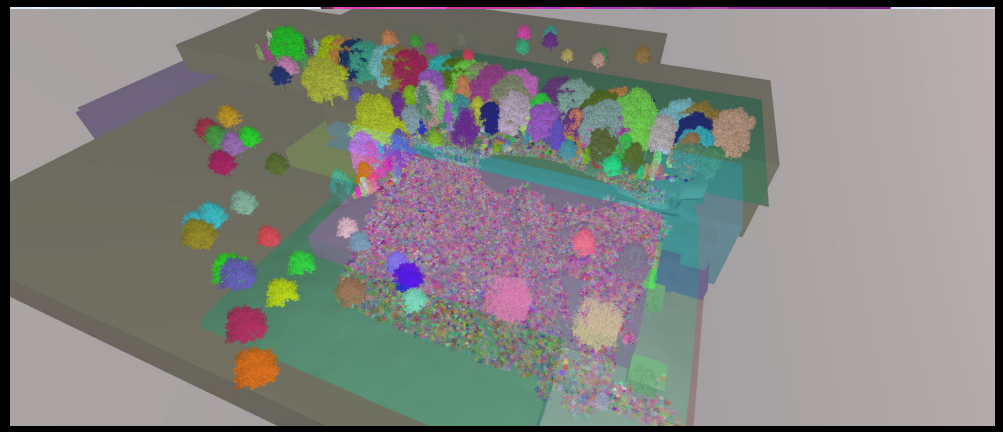

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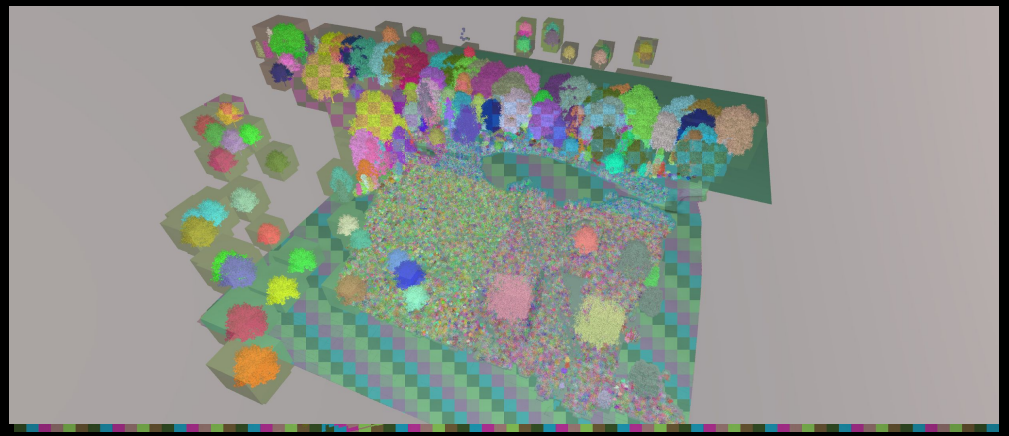

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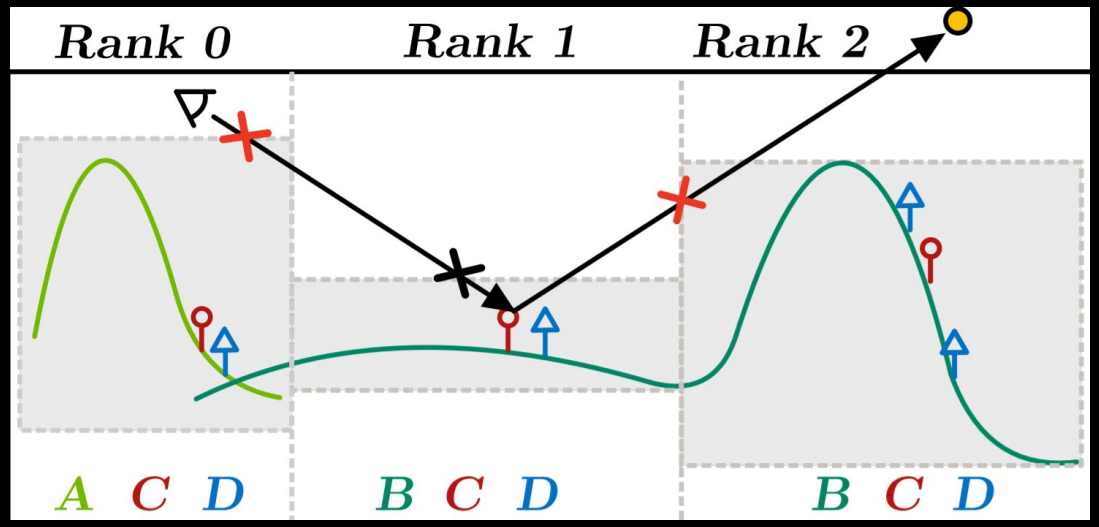
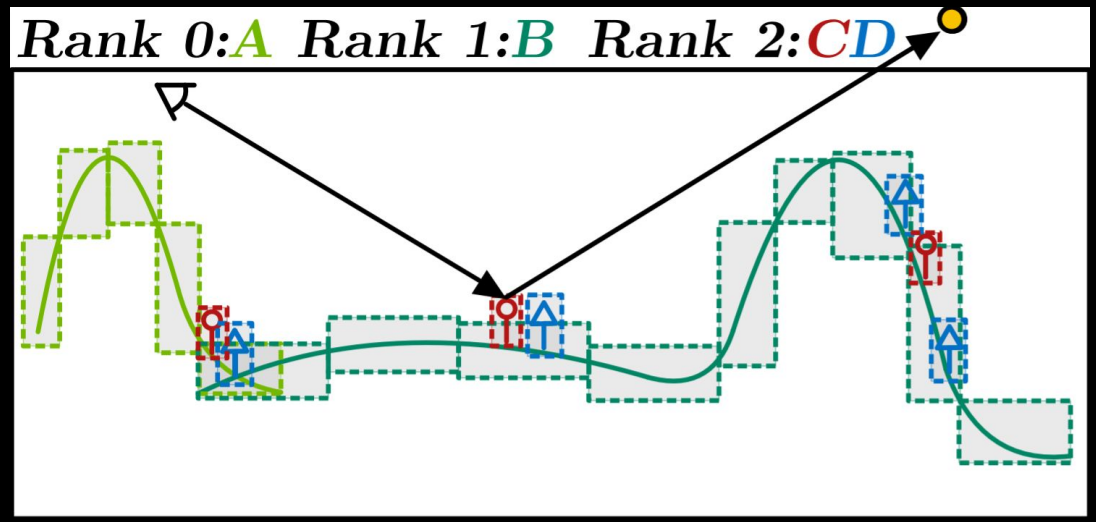
Spatial vs Object with Spatial Split?

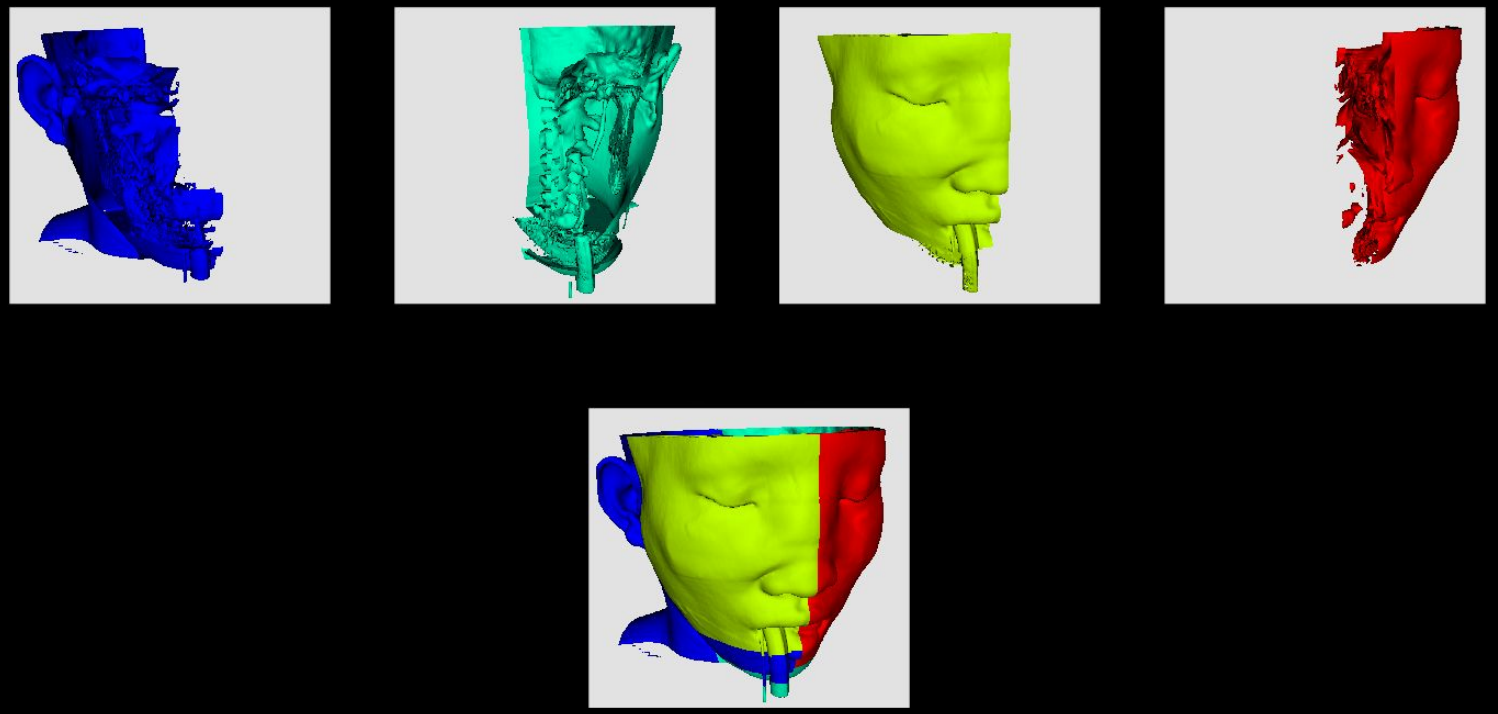




- In this motivational example: actually better in partitioning and ray forwards!
- Question: “How”.
  - In particular, how do we traverse this?

(Data-)Parallel Rendering : How ?

- Data-parallel rendering: mult.nodes work together
- Most used today: “sort-last” image compositing
  - Easy, fast, well understood, widely used in Sci-Vis



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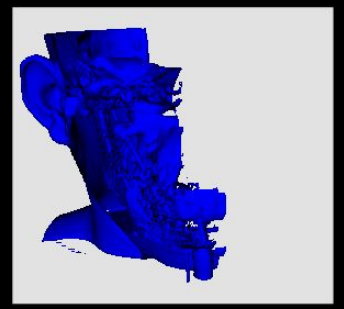
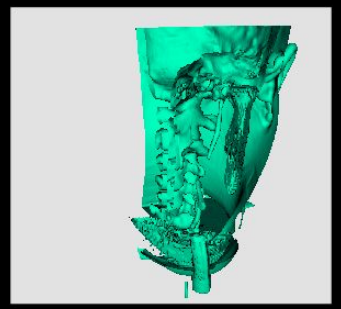
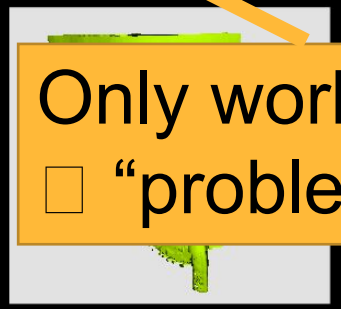
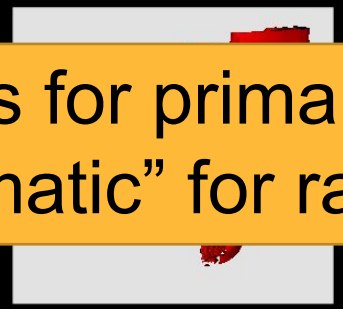
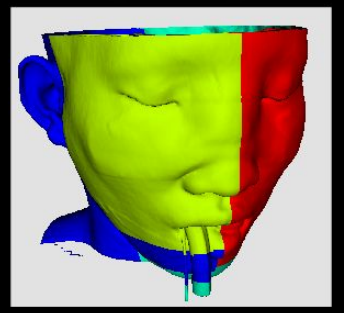
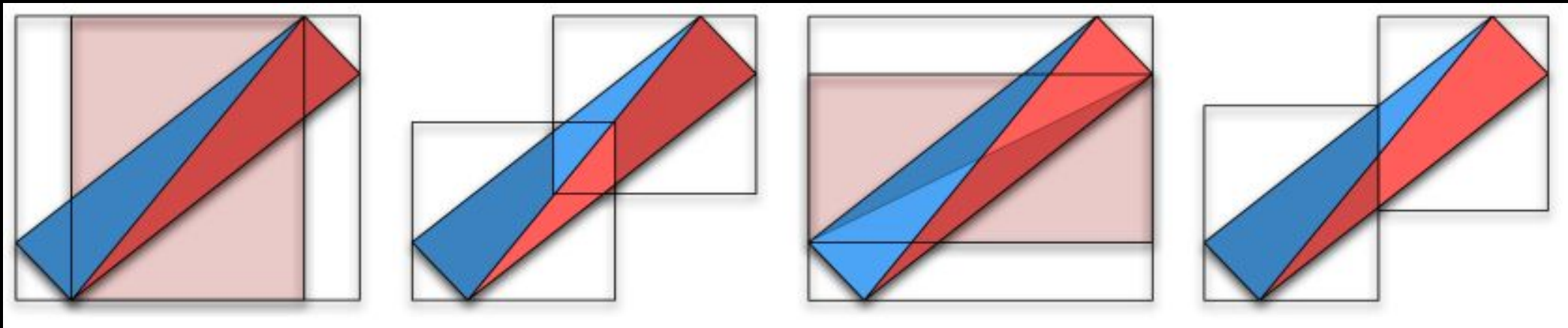





Only works for primary rays
 “problematic” for ray/path tracing



Huh – overlap of large objects …

- Same problem as large tris in BVH building
  - E.g.: Stich et al, Spatial Splits in Bounding Volume Hierarchies:
    - don’t split object itself, but represent with multiple, tighter-fitting boxes!



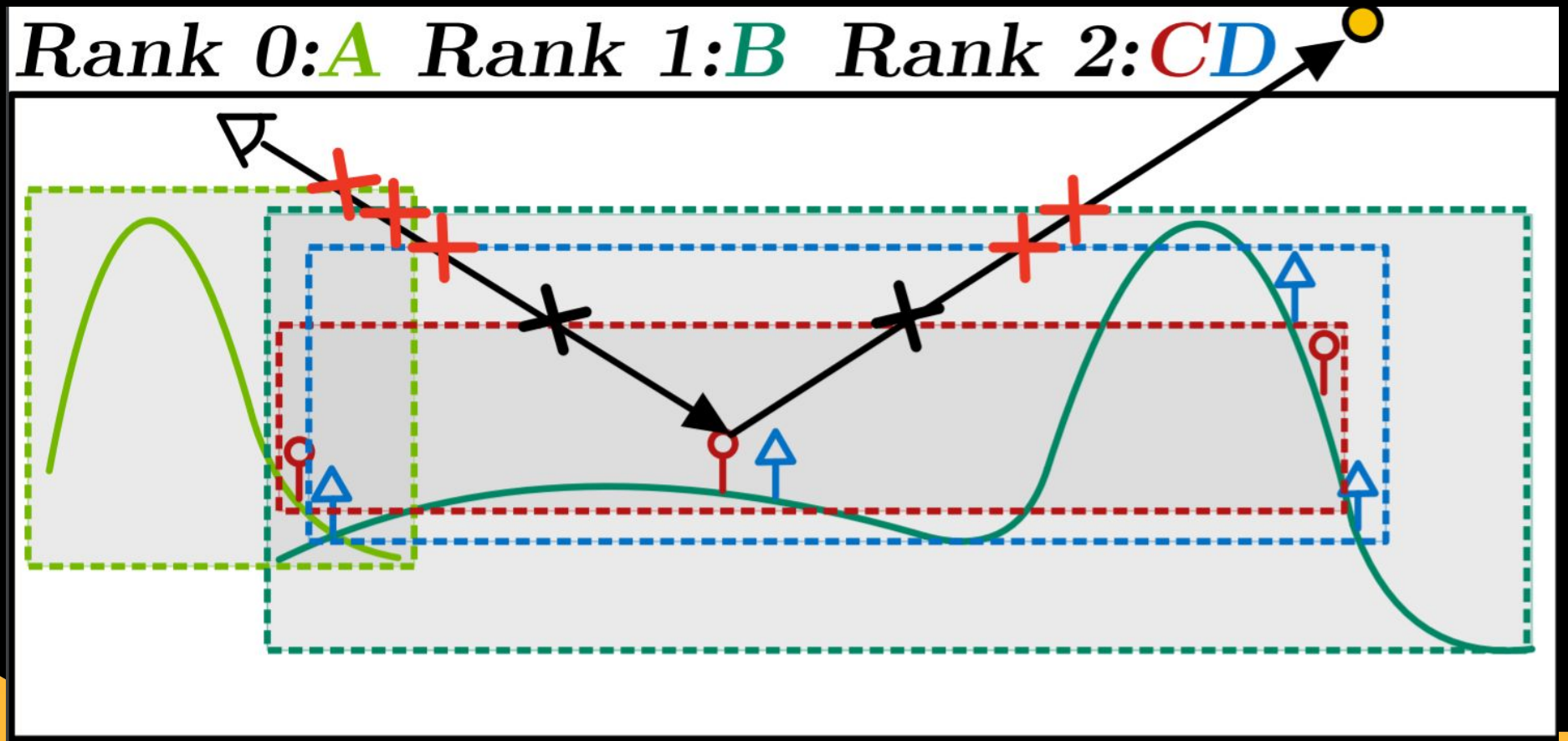
  - Also “re-braiding”: similar approach for instances

- Can do exactly the same on partitioning problem

Applying spatial splits & re-braiding eqiv.

- Let's simply put A to rank 0, B to r
  others to rank 2 …

"pure" object space w/ large instance bounding boxes



Proxies

- Naïve: one proxy / inst, each inst on one rank
  - But: could also have more than one inst in a proxy…
  - … or more than one proxy per any geom…
  - … or even replicate some insts to more than one rank