OpenFLAME

# Federated Maps to Enable the Spatial Web

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CMU


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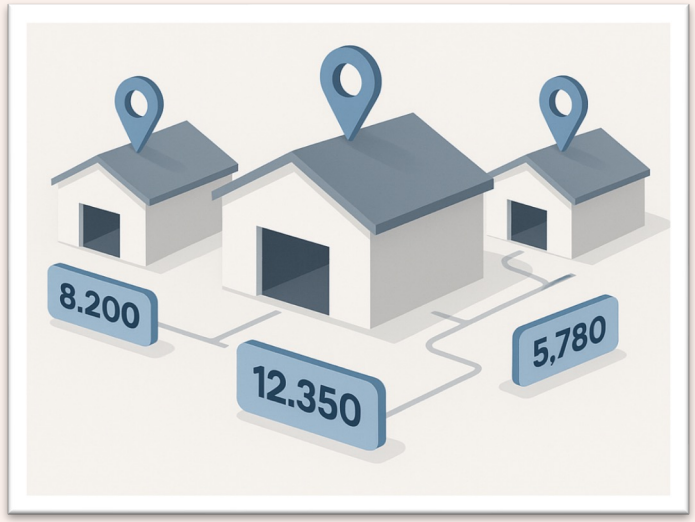
Anthony Rowe

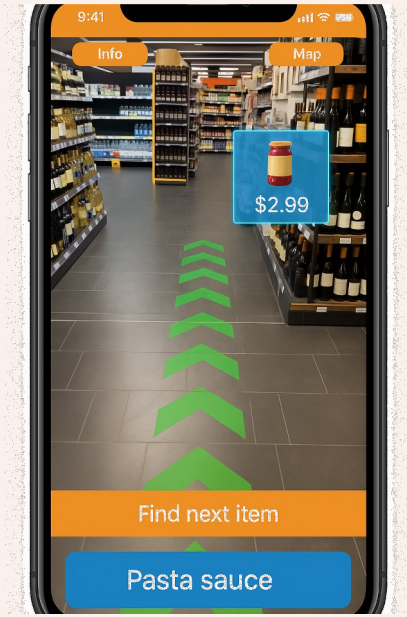

Srinivasan Seshan

# Examples of Spatial Applications

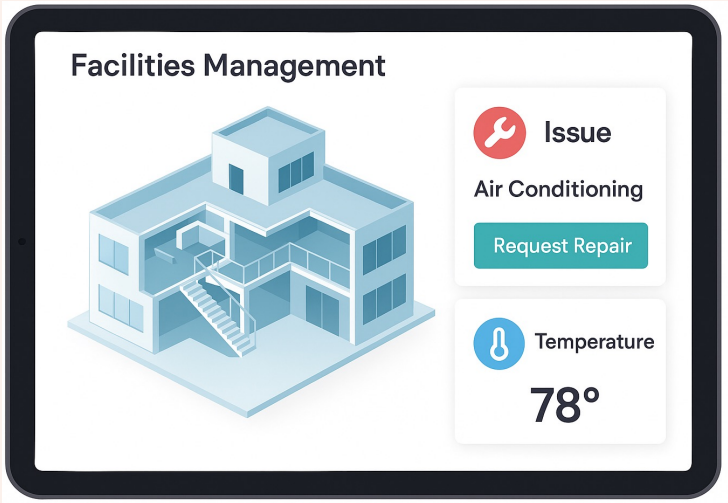
3D indoor navigation




Inventory management

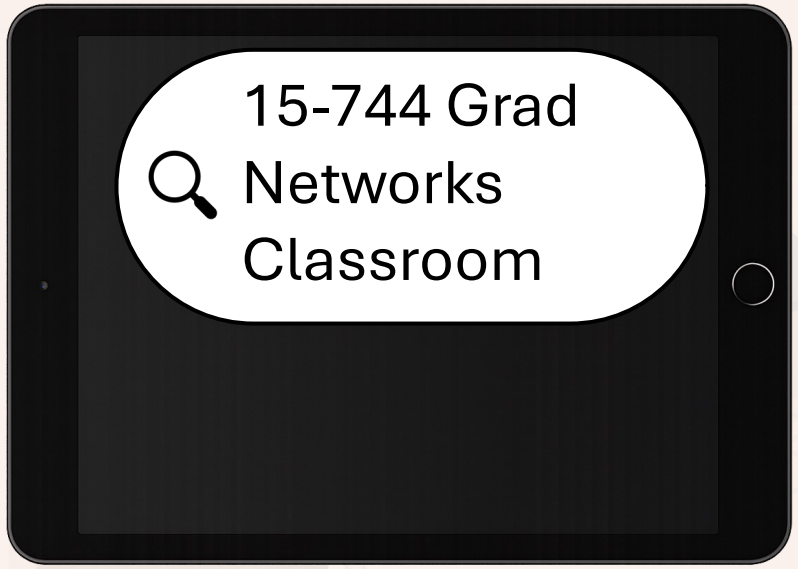



AR shopping



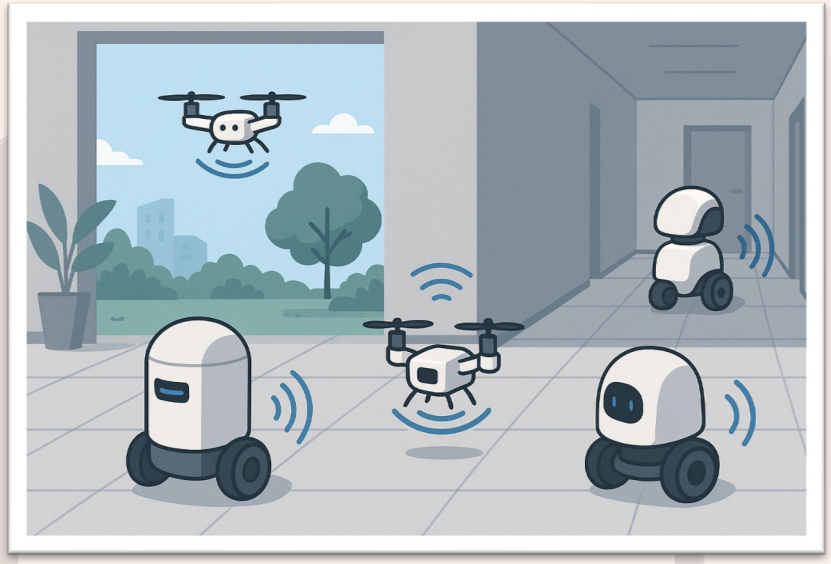

Facilities management

# Examples of Spatial Applications




Fine-grained location search

Placing AR content



Autonomous Robots

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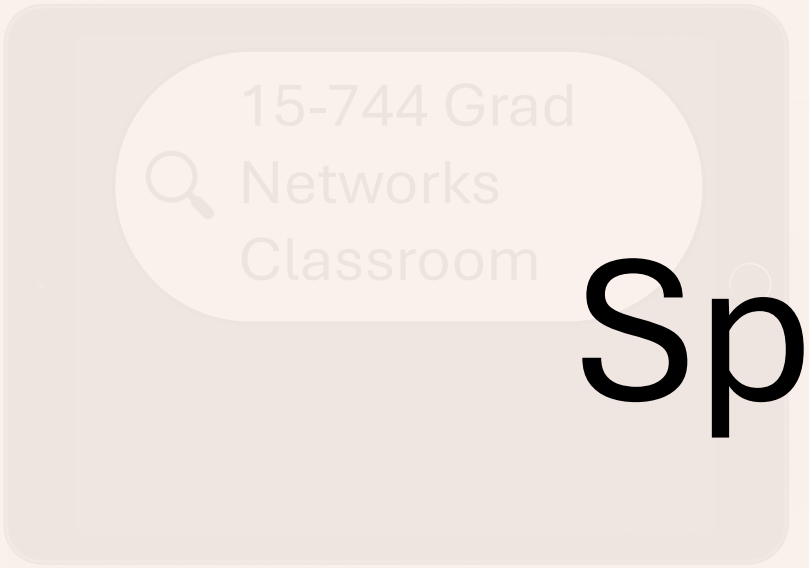


Fine-grained location search

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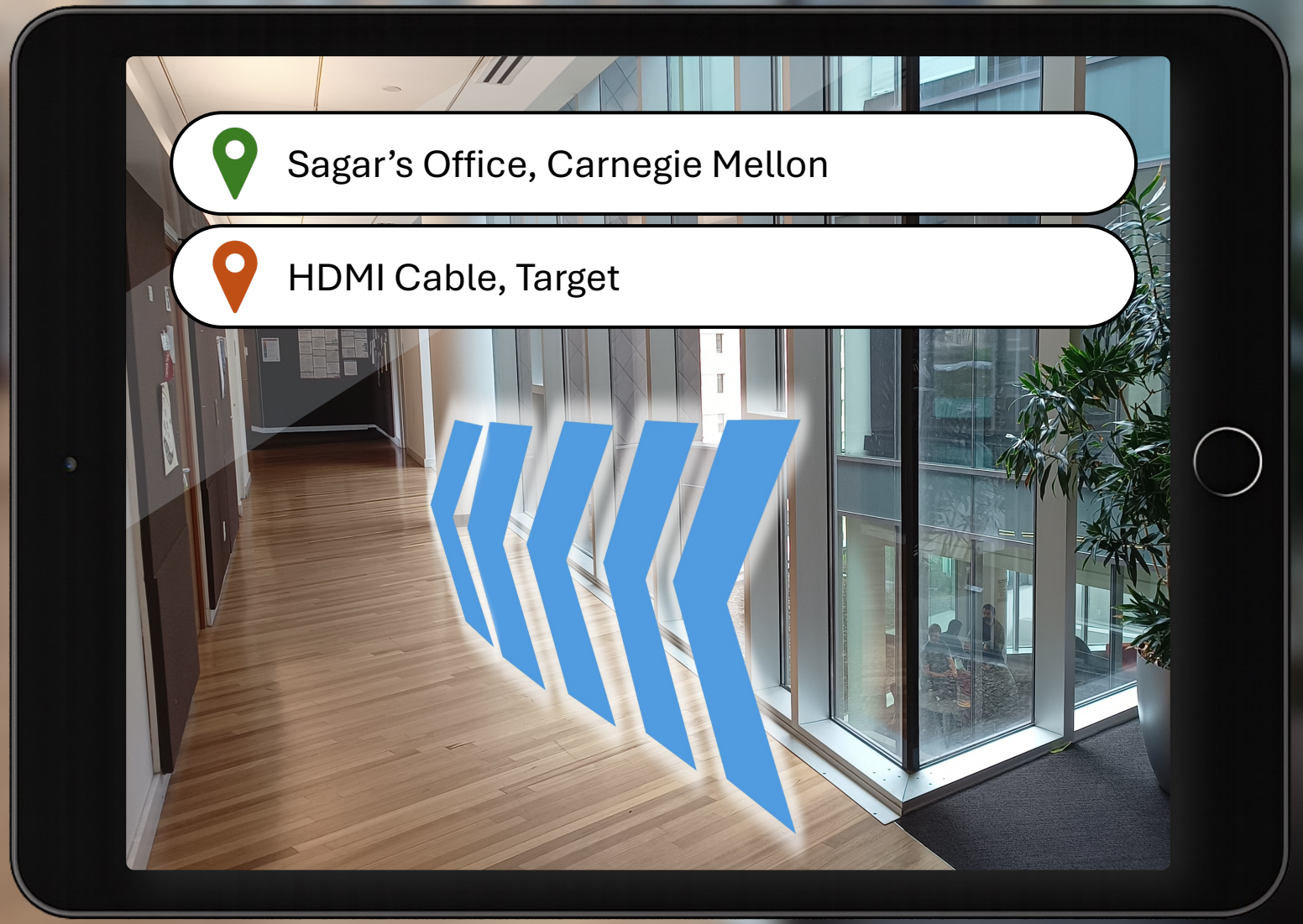
Autonomous Robots

Spatial Web

# Motivating Example: Navigation

# Example Application: Shopping Navigator



# Example Application: Shopping Navigator

Sagar’s Office, Carnegie Mellon

HDMI Cable, Target

We need a system to associate this name with a real-world location
...or a **Spatial Naming System** a.k.a **Map**

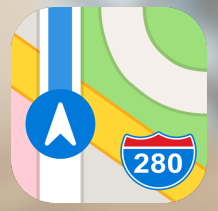
# Example Application: Shopping Navigator

Sagar's Office, Carnegie Mellon

HDMI Cable, Target

Today, to build such an application, we would use a digital world map

Google Maps



Apple Maps


mapbox


OpenStreetMap

# Example Application: Shopping Navigator

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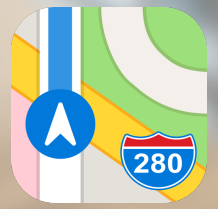
HDMI Cable, Target

Today's maps answer only a part of the problem


Google Maps



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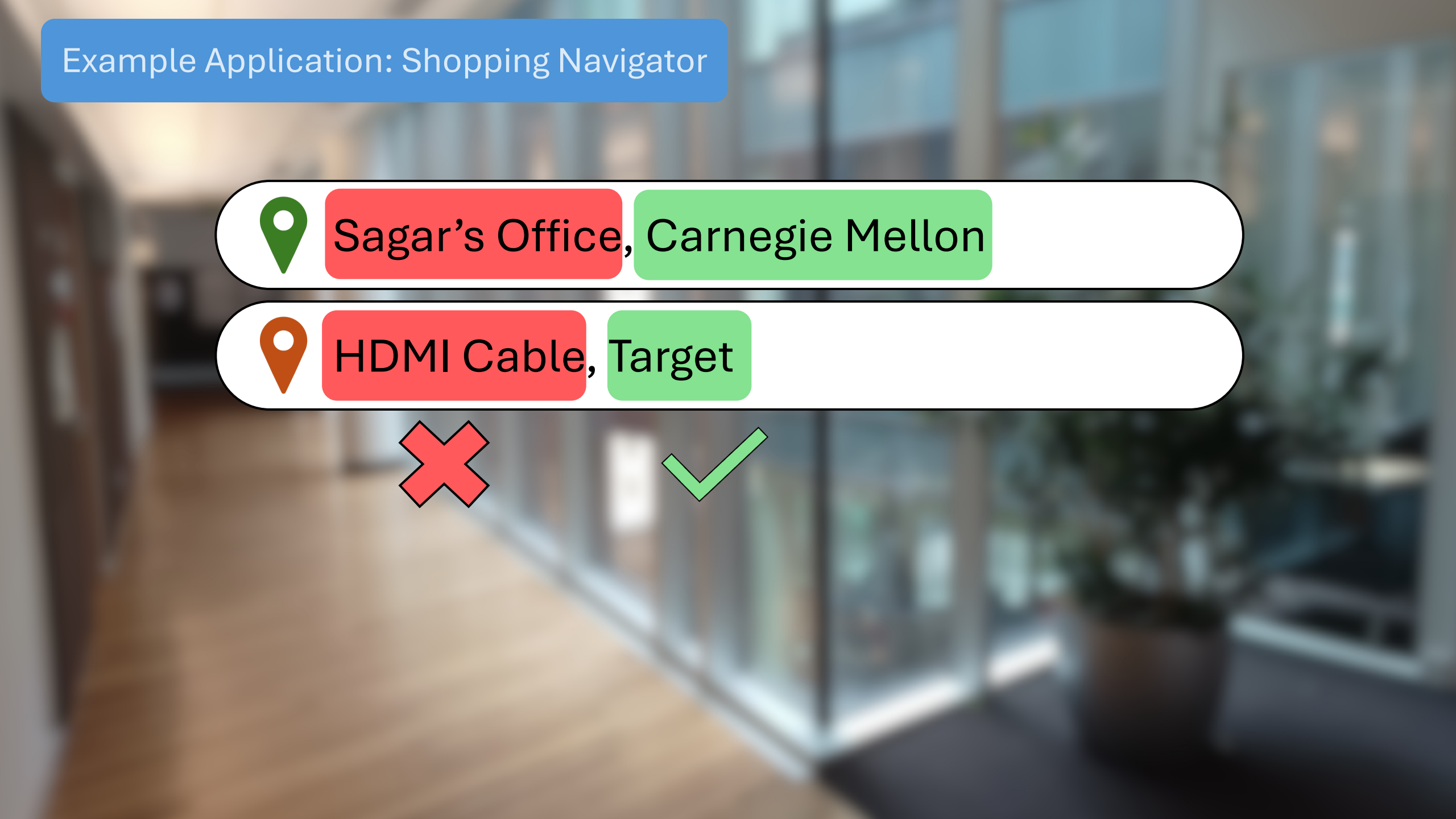
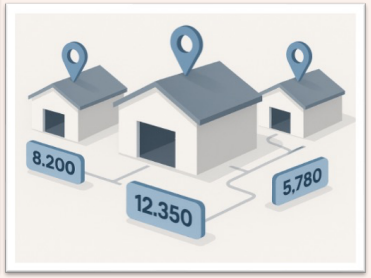


Indoor 3D navigation

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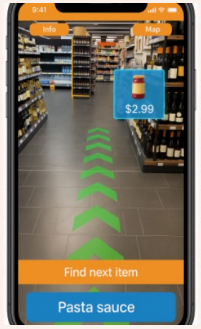


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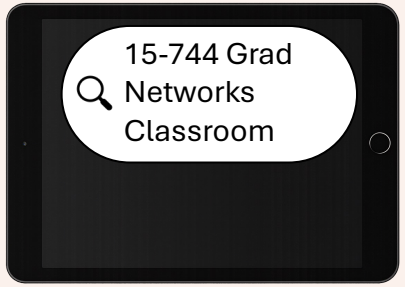


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# We need a ubiquitous Spatial Naming System to enable emerging Spatial Applications

# Why do maps today not have ubiquitous coverage?

Indoor data collection is hard

Crowdsourcing on a central system is not the right way to scale

# Why do maps today not have ubiquitous coverage?

Indoor data collection is hard

Crowdsourcing on a central system is not the right way to scale

Huge manual cartography effort.

Many indoor spaces are private.

Indoor maps are dynamic.


Outdoor cartography

Indoor cartography

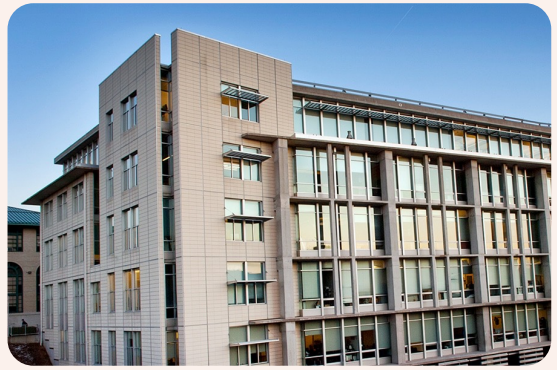
# Why do maps today not have ubiquitous coverage?

Indoor data collection is hard

Crowdsourcing on a central system is not the right way to scale

Businesses do not want to expose their indoor map data due to privacy and competition concerns.

NSA



CMU CIC

Single Family Home

# Federation of Maps

Independent organizations maintain their own maps of their own spaces.

# Federation of Maps

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# Federation of Maps

maps.cmu.edu

# Federation of Maps

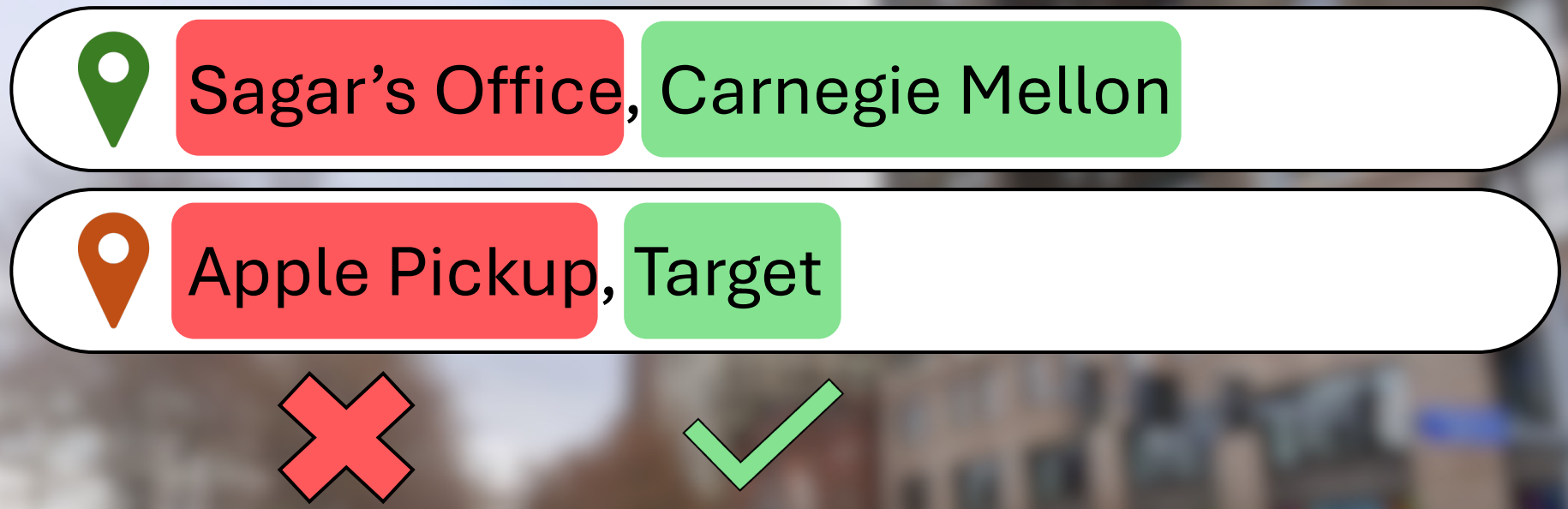
# Federation of Maps

# Federation of Maps

OpenFLAME

Ties maps together

# Example Application: Shopping Navigator



# Example Application: Shopping Navigator

Sagar's Office, Carnegie Mellon

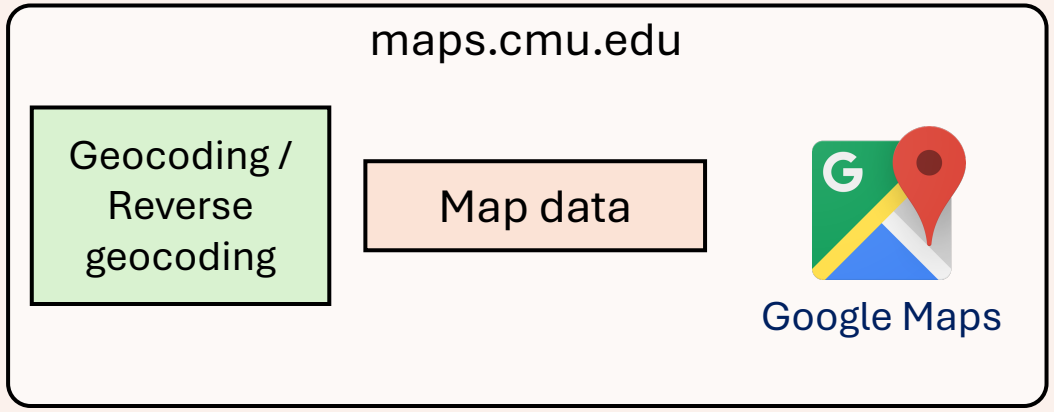
Apple Pickup, Target

Target Maps


CMU Maps

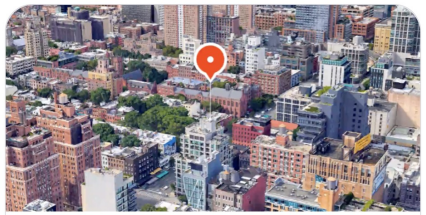
Google Maps

# Design—a Centralized Spatial Naming System




**Geocoding**: Convert addresses to corresponding geographic coordinates.

# Design—a Centralized Mapping Platform



Aerial View

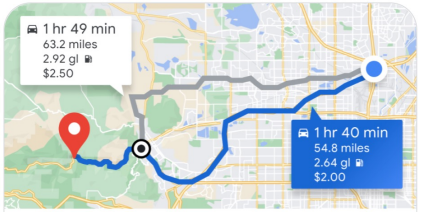
PRO

Dynamic Maps

ESSENTIALS

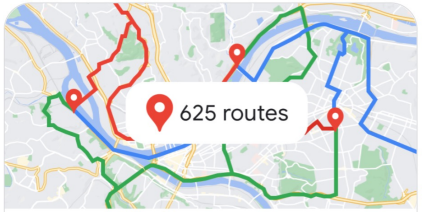

Elevation

PRO




Compute Routes

ESSENTIALS PRO ENTERPRISE

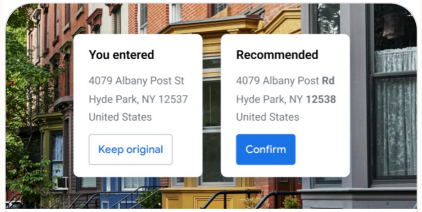



Compute Routes Matrix

ESSENTIALS PRO ENTERPRISE

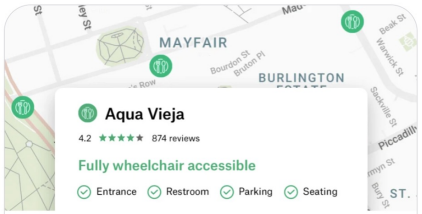
Navigation SDK

ENTERPRISE



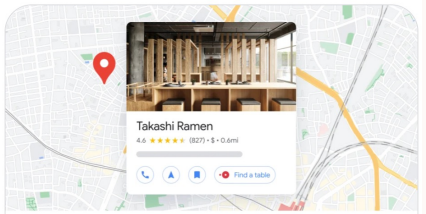

Address Validation

PRO ENTERPRISE




Nearby Search

PRO ENTERPRISE



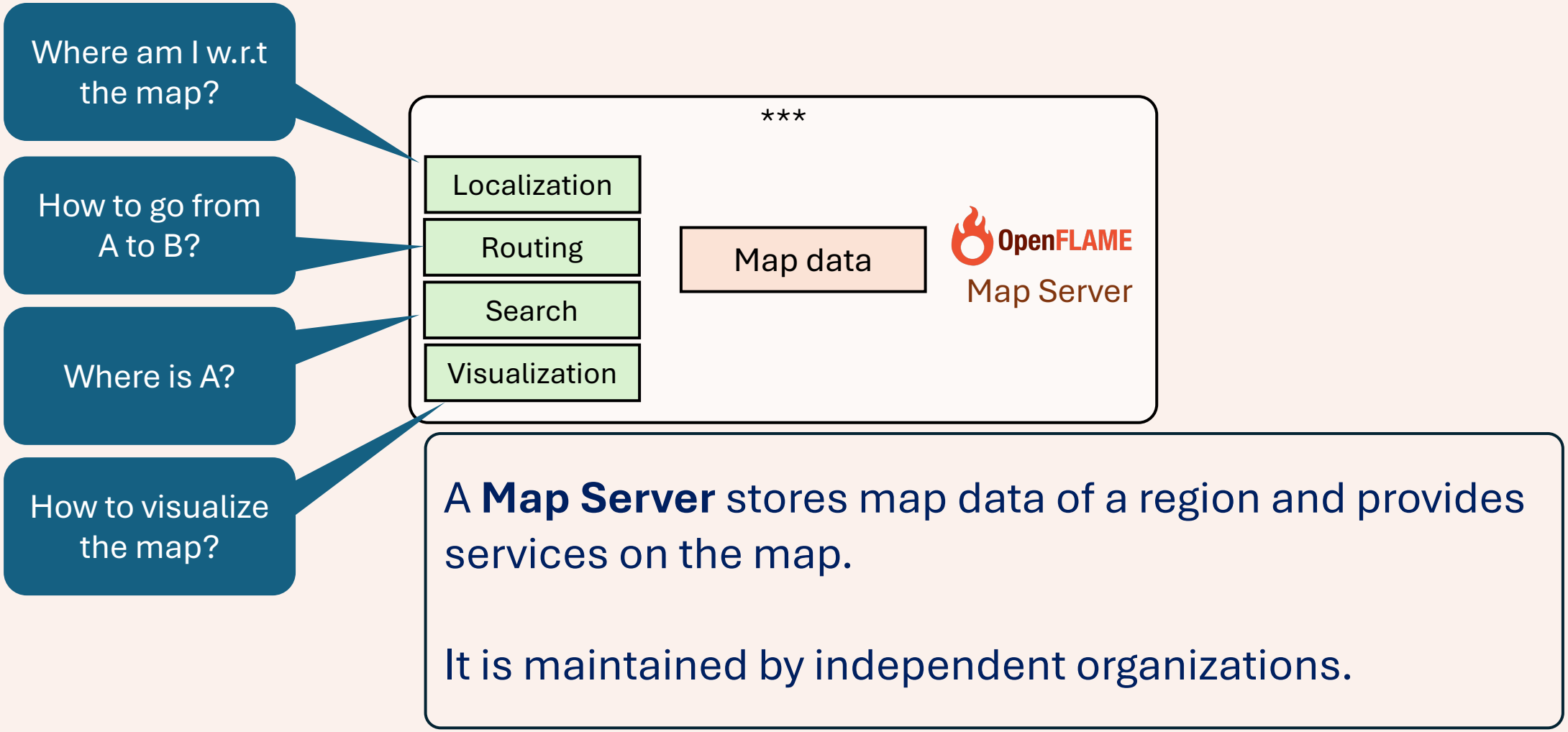

Place Details

ESSENTIALS PRO ENTERPRISE

Map data

Google Maps

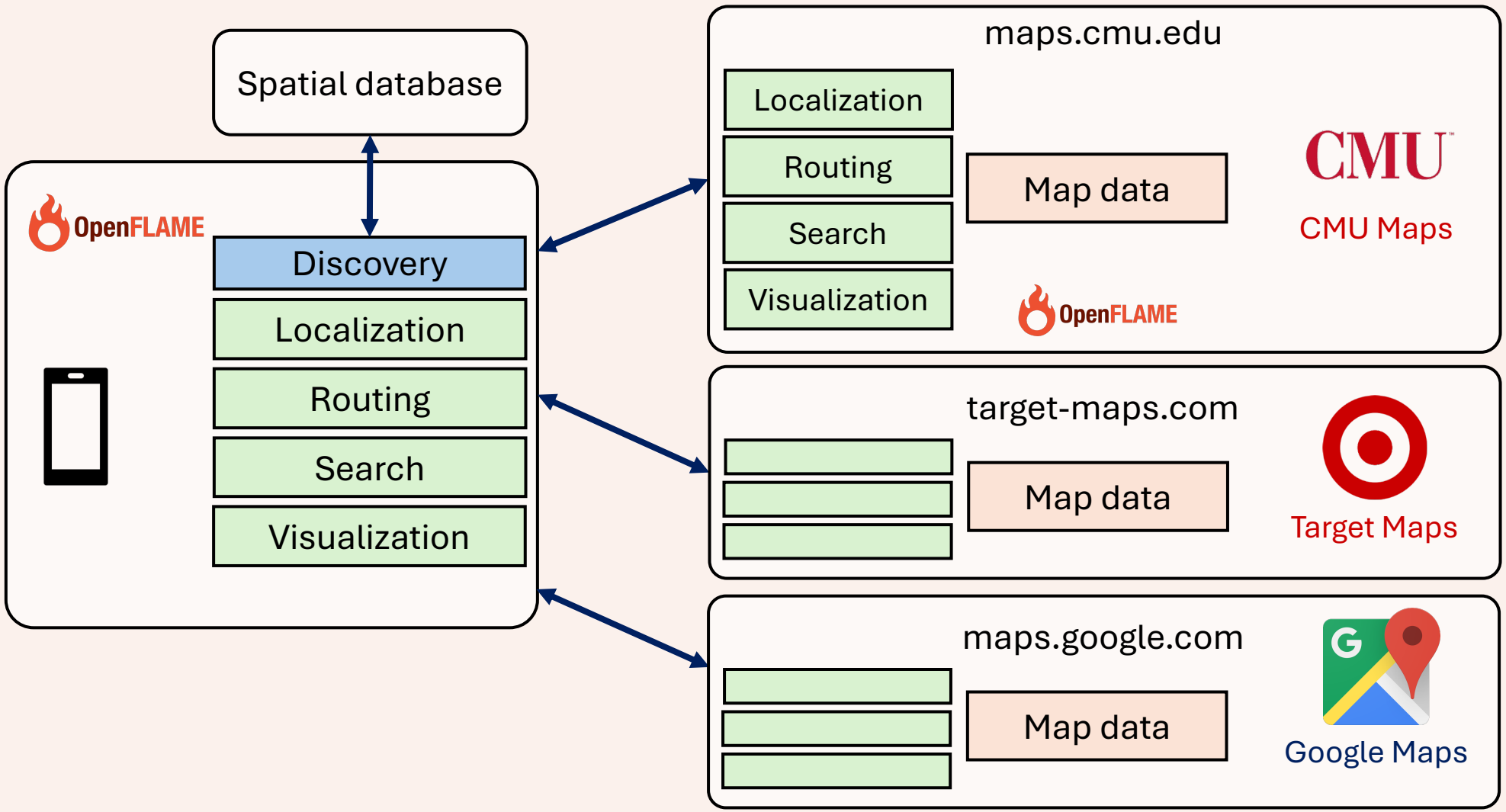
# Design—OpenFLAME Map Server



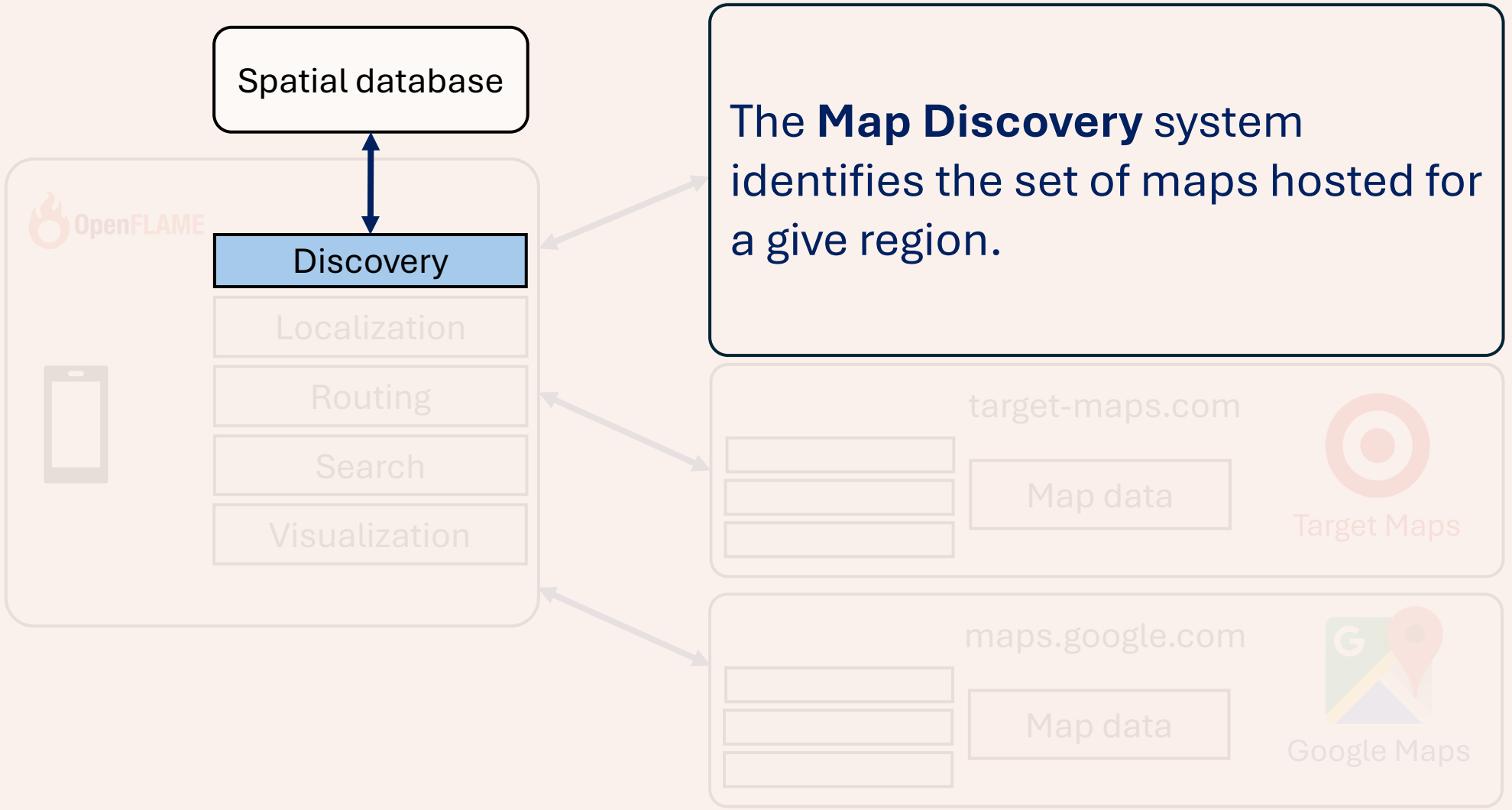

A **Map Server** stores map data of a region and provides services on the map.

It is maintained by independent organizations.

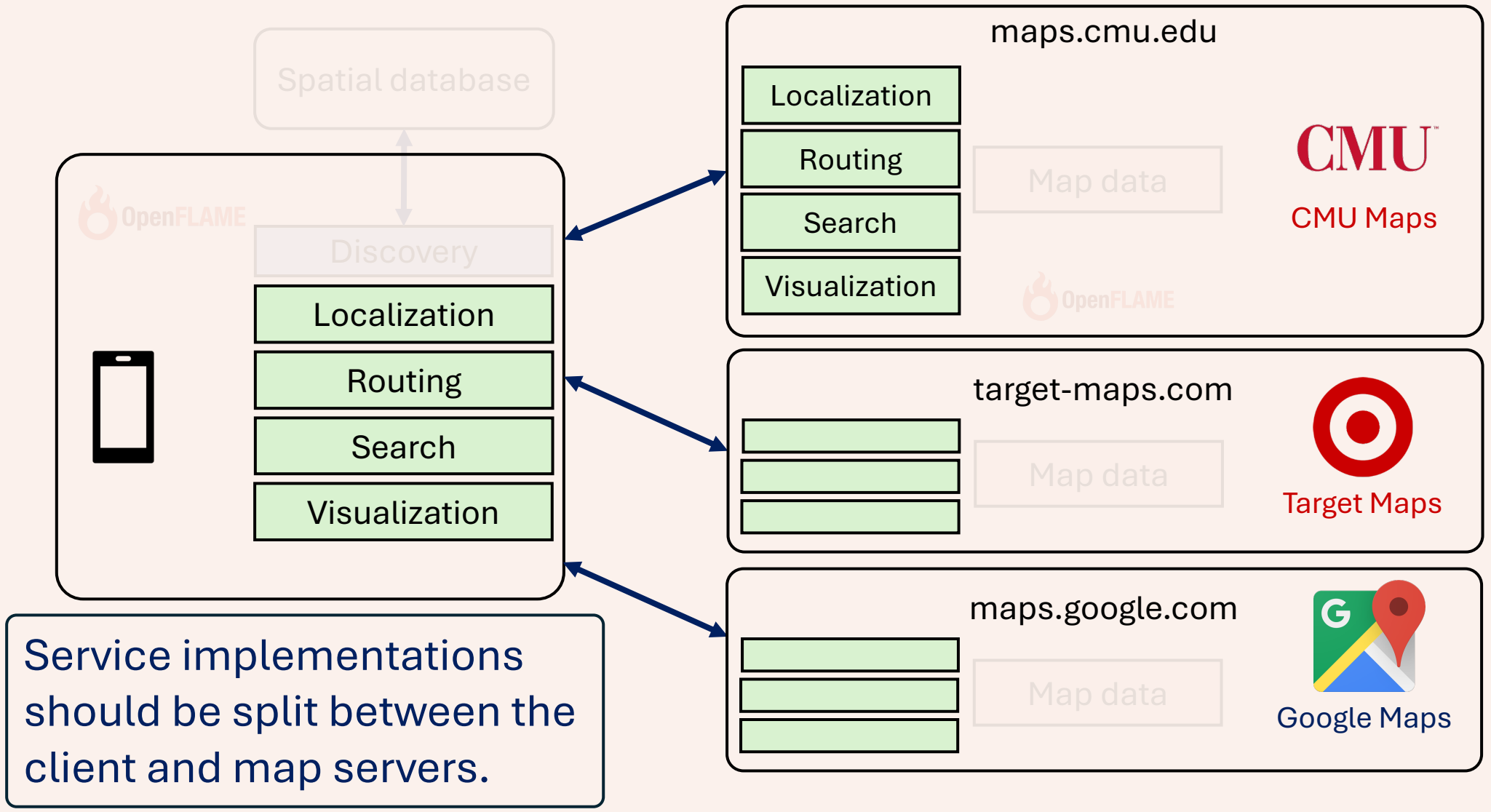
# Design of OpenFLAME



# Design—Map Discovery



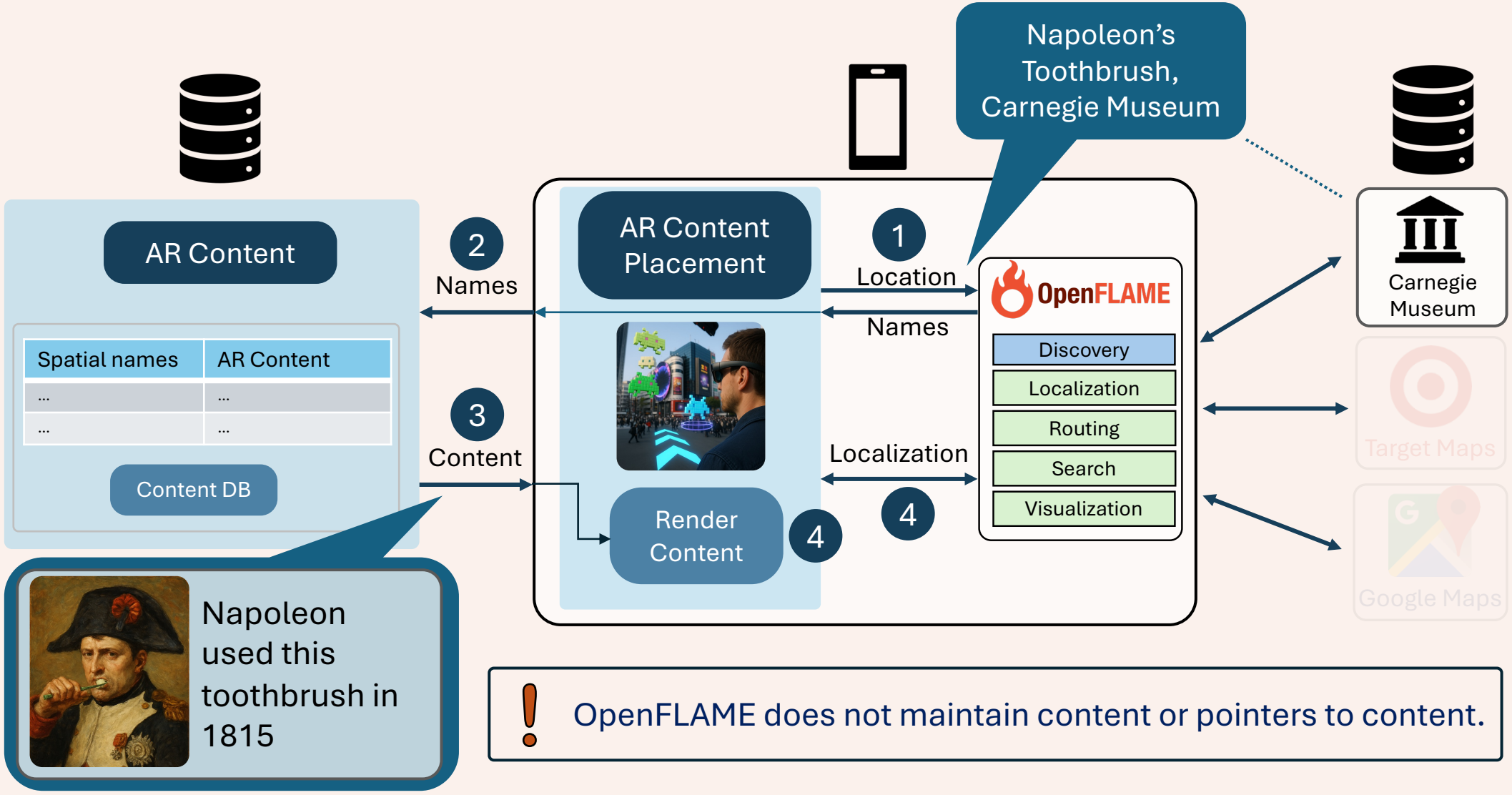
# Design—Map-based Services




Service implementations should be split between the client and map servers.

# Example Application

# Example: Application Design



# Federation offers benefits

Privacy

Fine-grained access control

Independence of services

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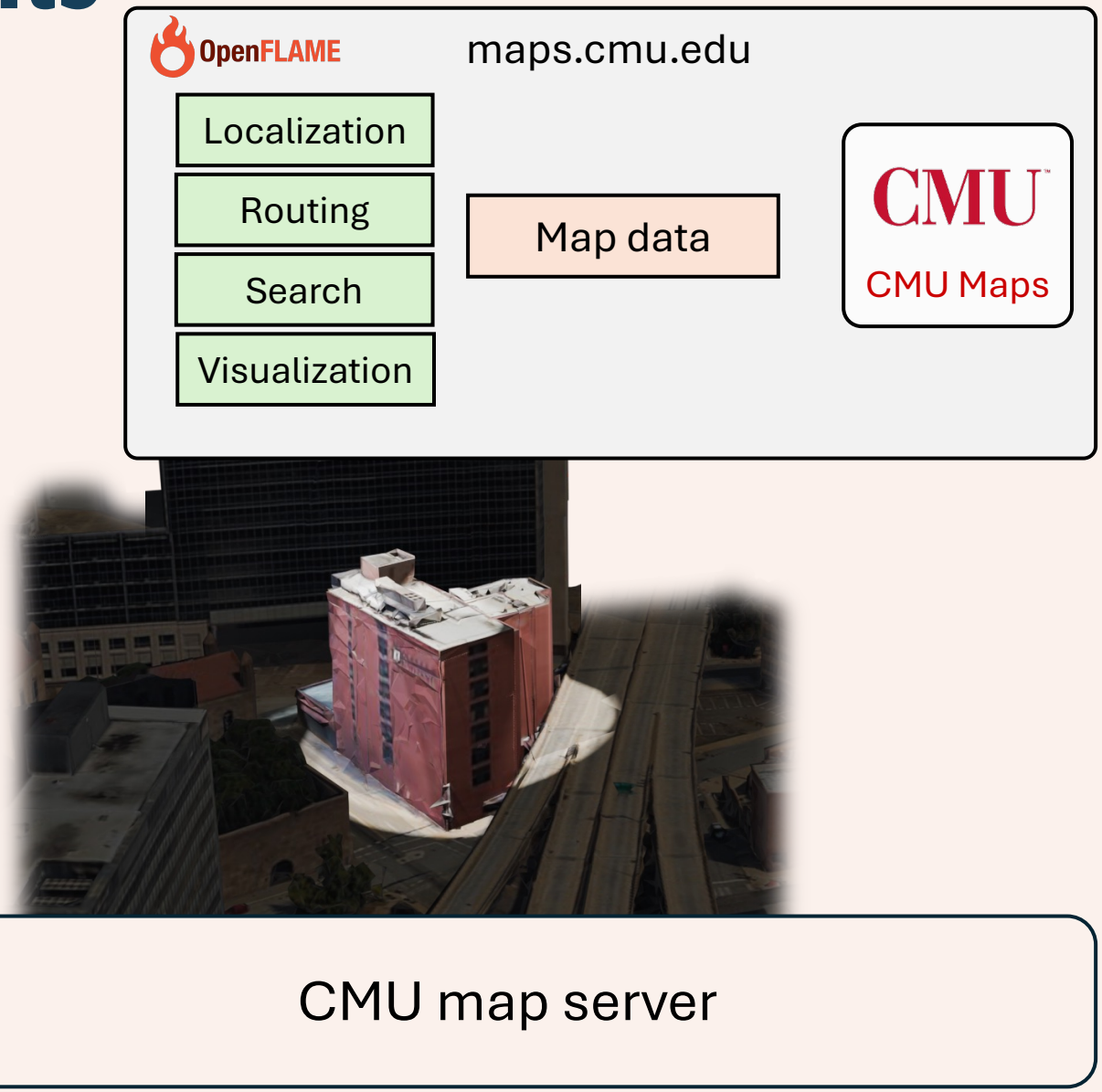

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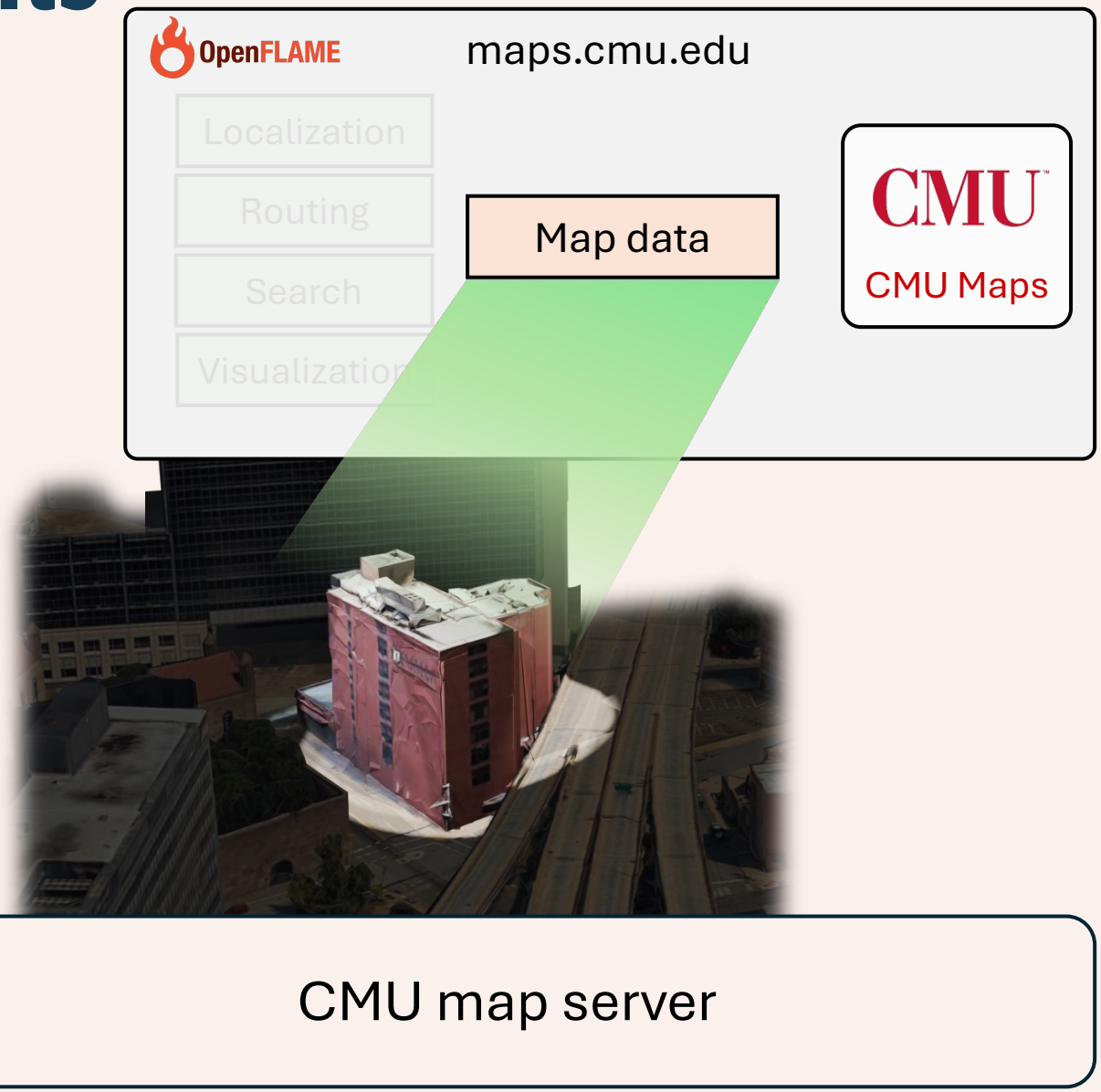

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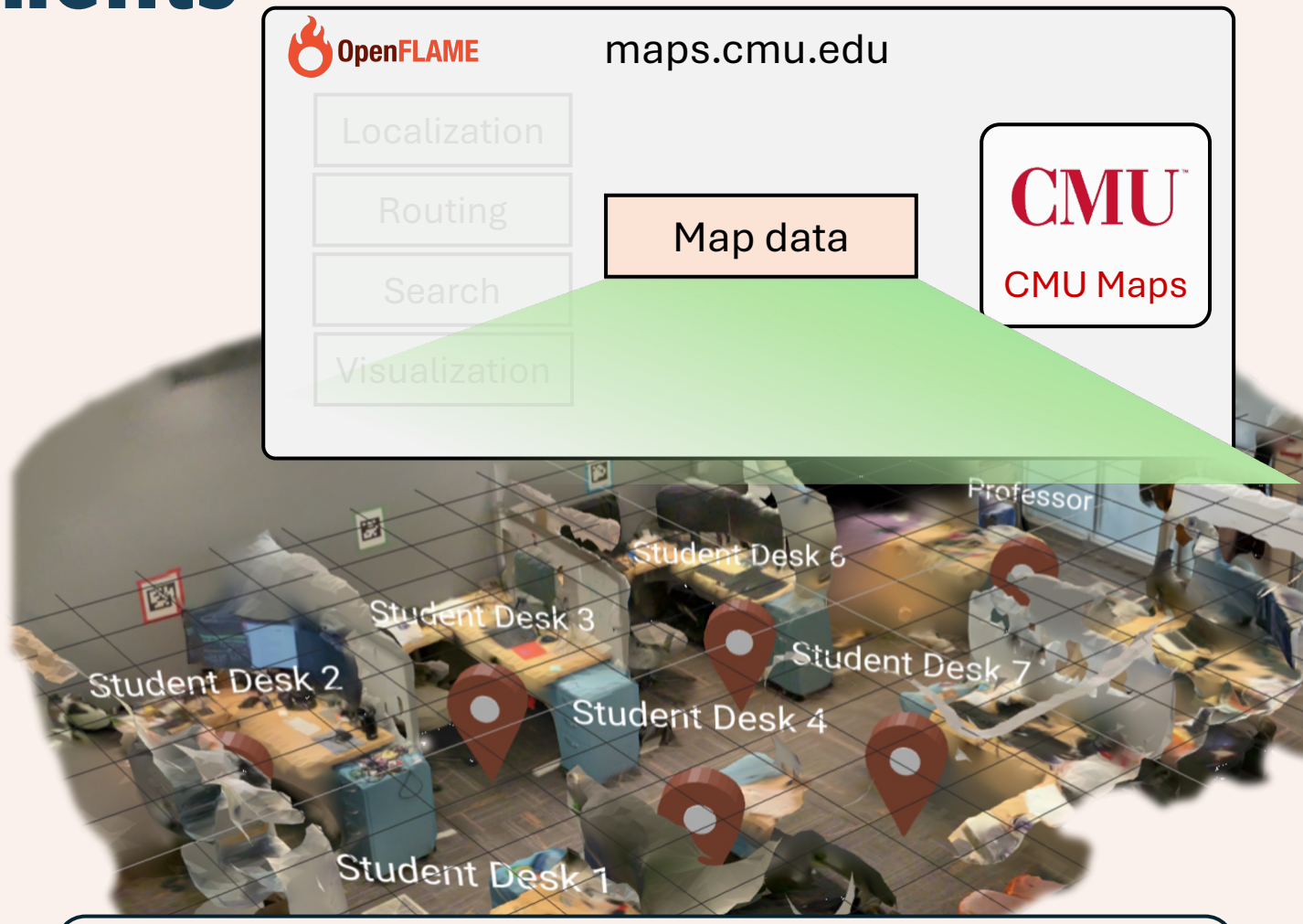


Private map data is stored on private servers.

# Federation offers benefits

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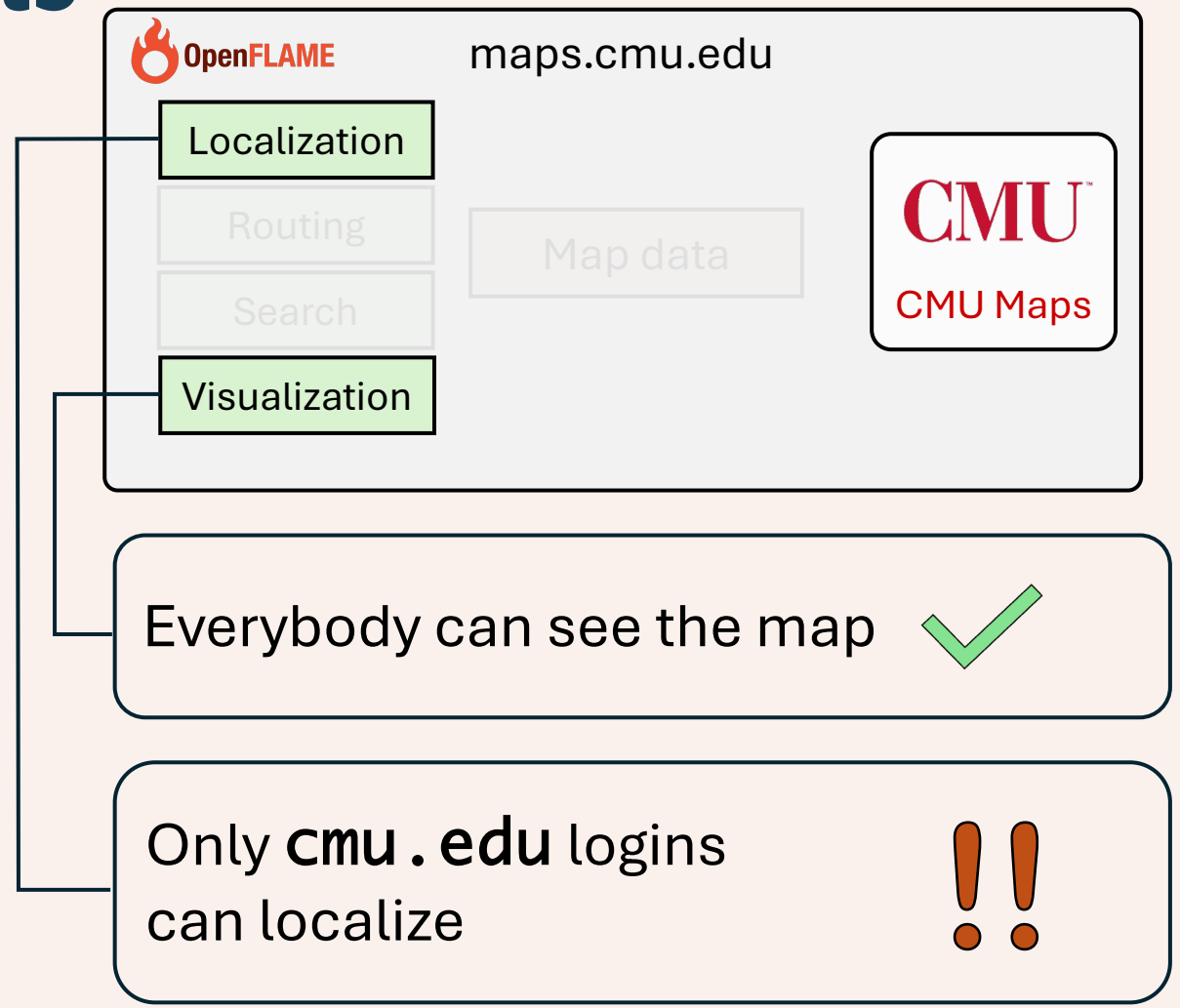

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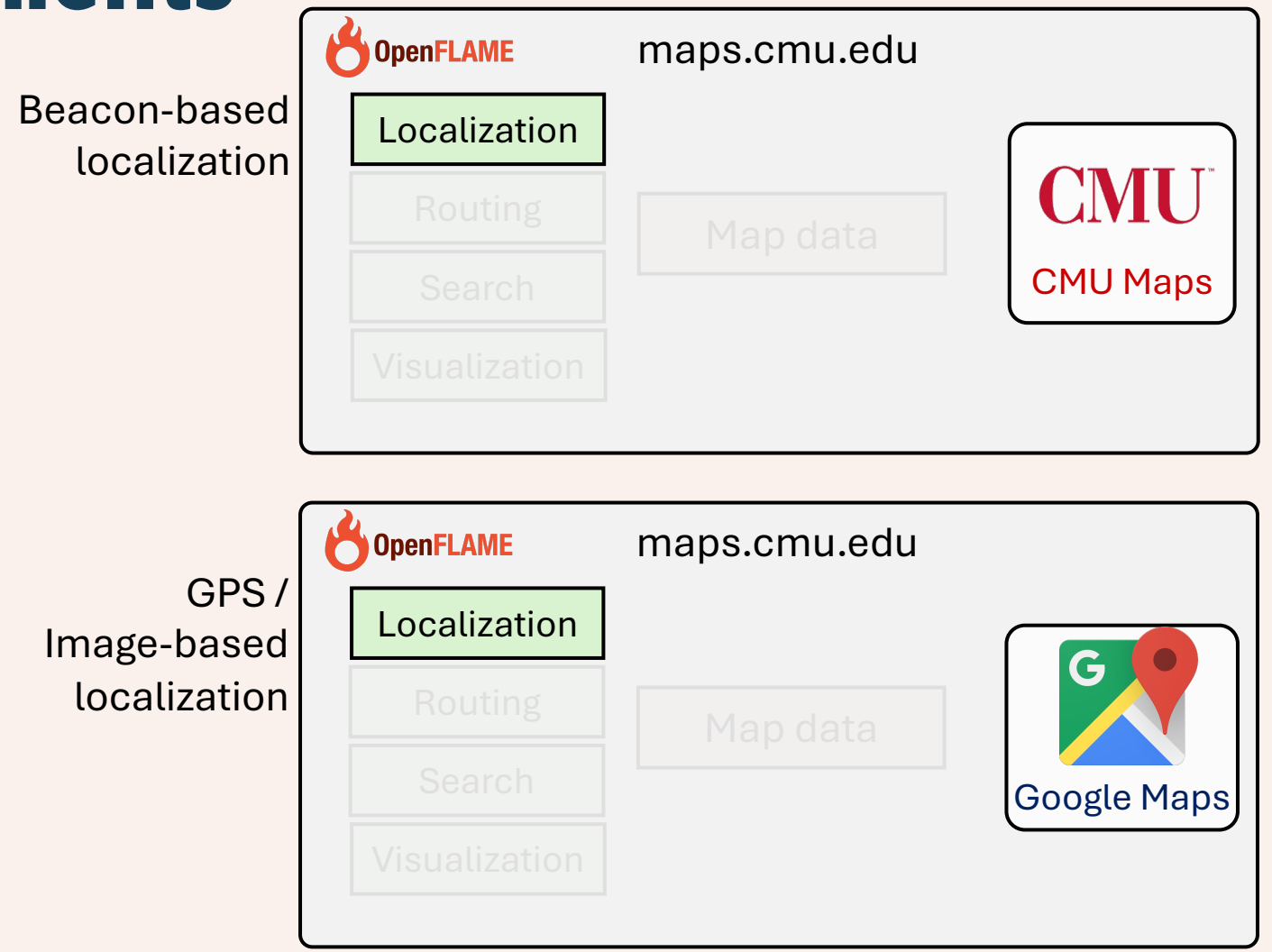

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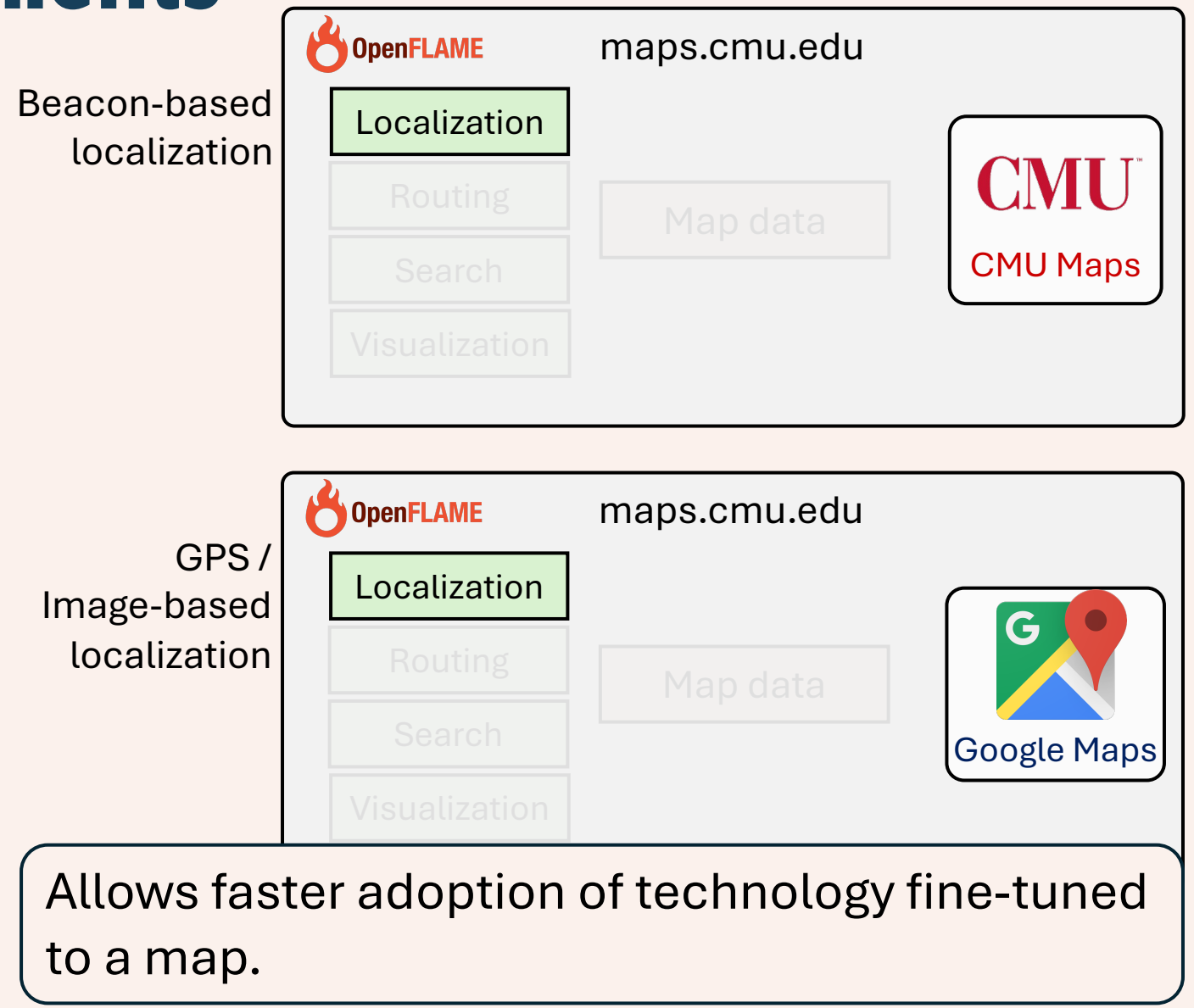


Allows faster adoption of technology fine-tuned to a map.

# Challenges of Federation

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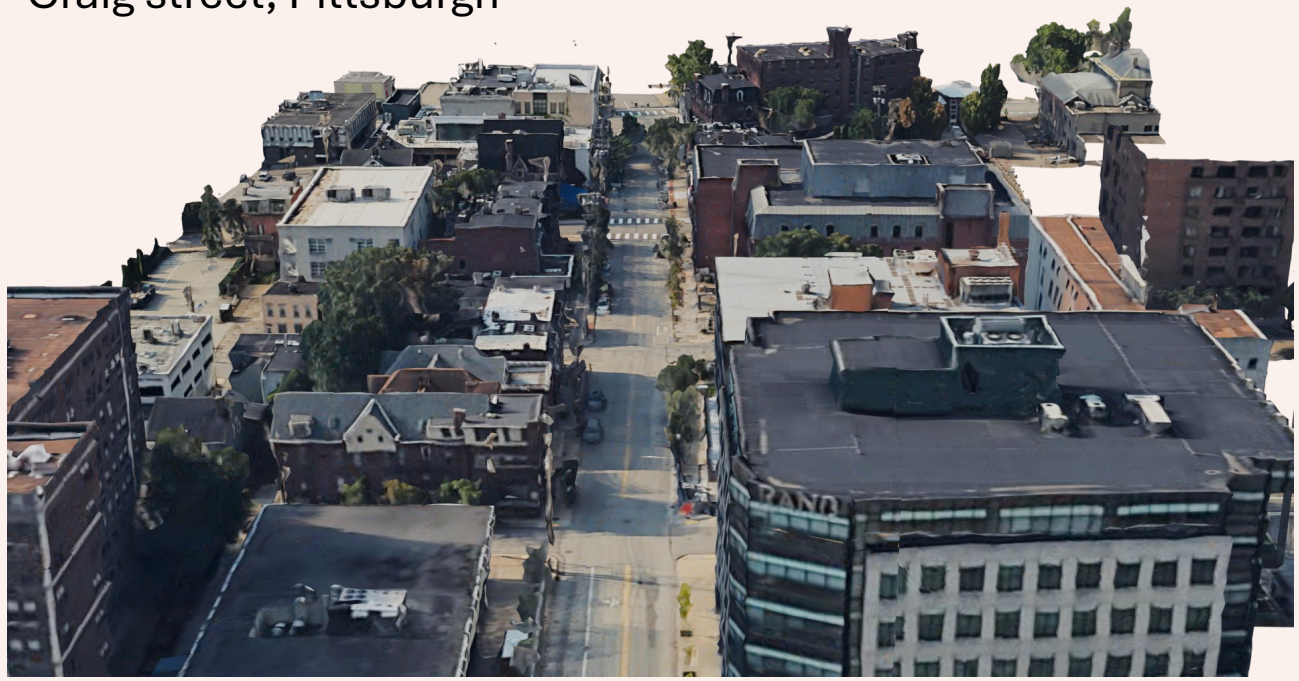
Design of map discovery

Ranking maps

Re-architecting services

Craig street, Pittsburgh



How do we discover all maps on this street?

# Challenges—Map Discovery

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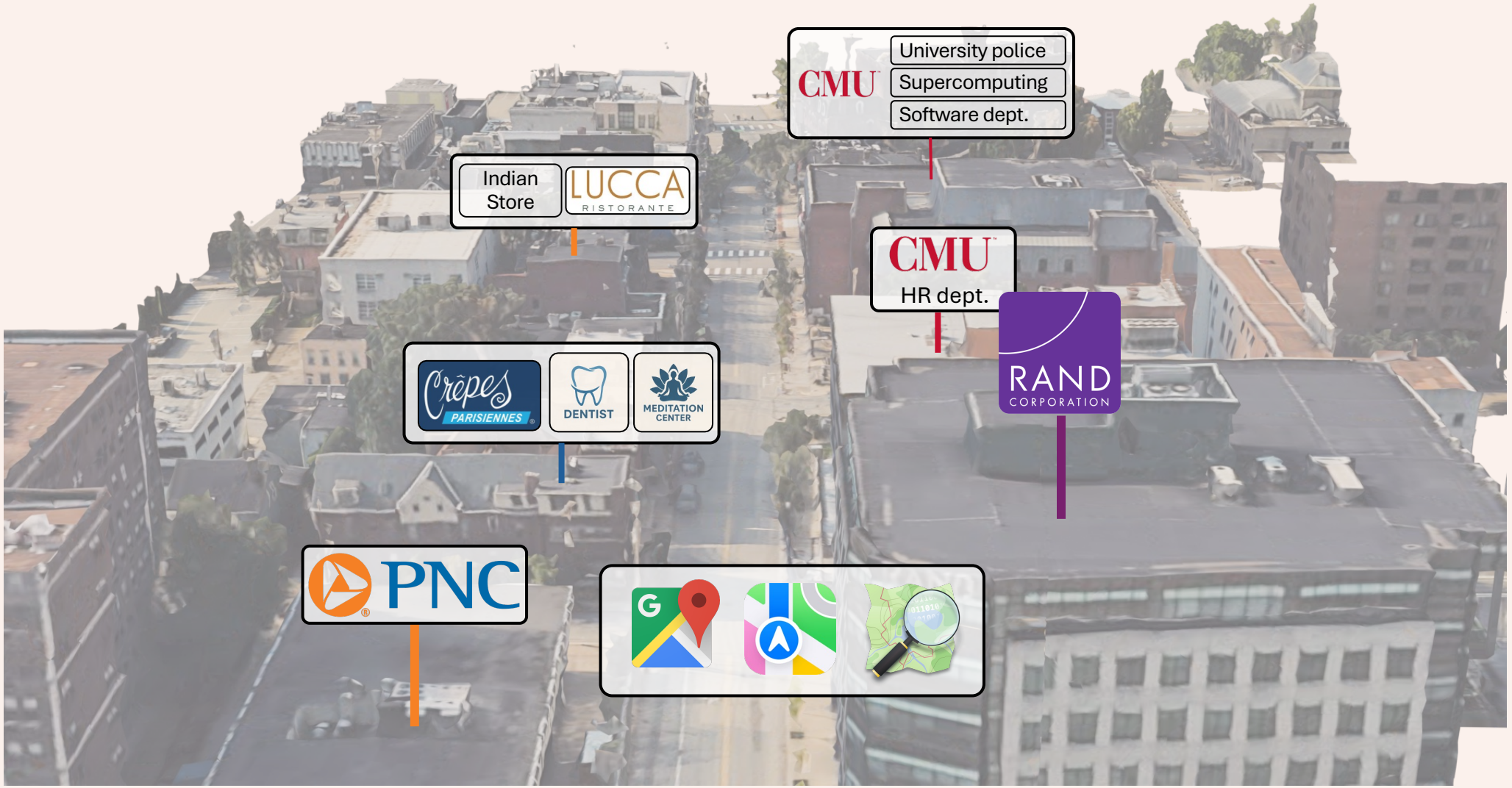
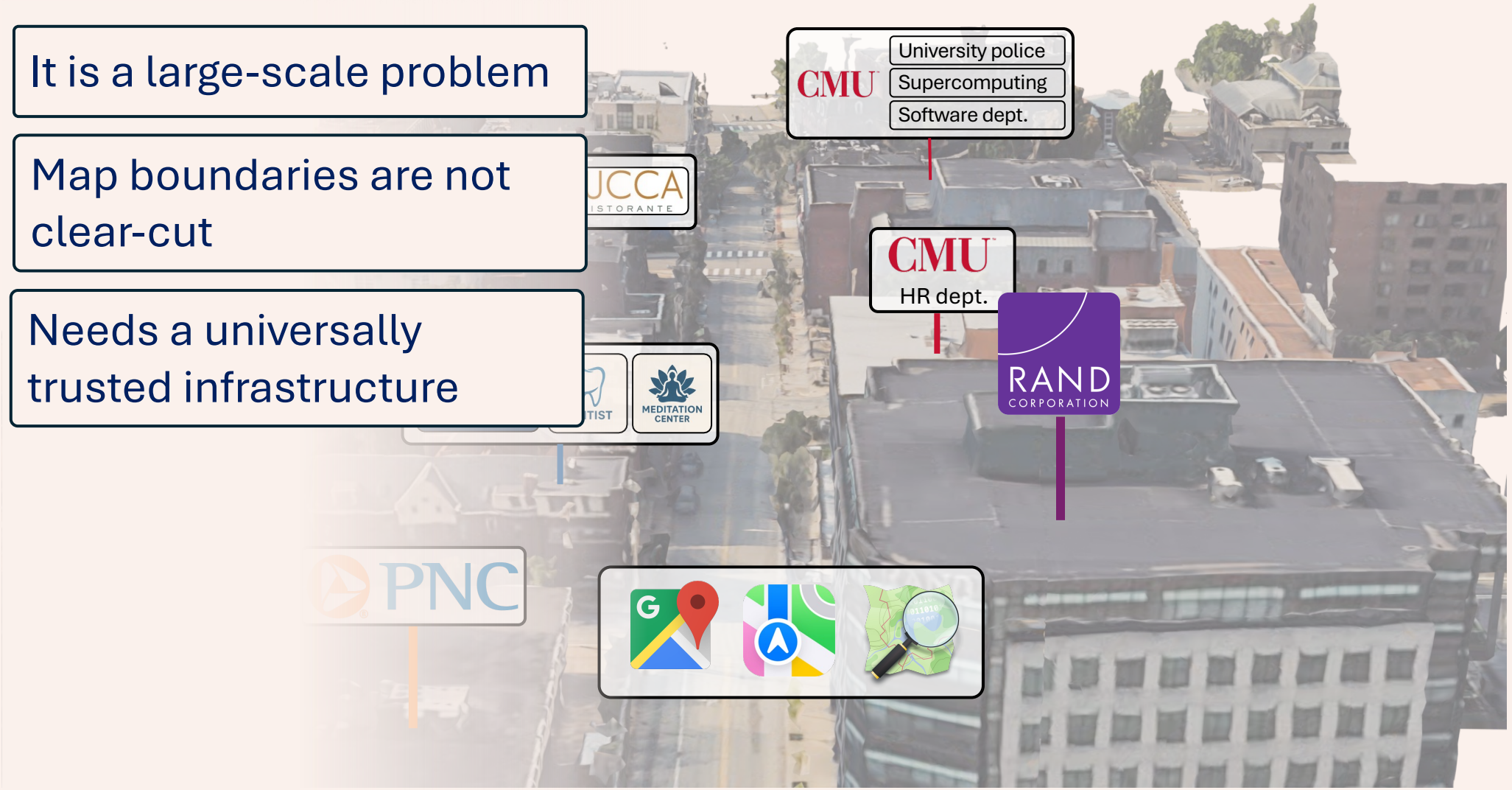


# Challenges—Map Discovery

It is a large-scale problem

Map boundaries are not clear-cut

Needs a universally trusted infrastructure



# Reusing existing trusted infrastructure—DNS

DNS has a widely deployed and trusted infrastructure with a multi-layered caching mechanism.

**We can use DNS as:**

Map boundaries are fuzzy.

Discovery queries do not need transaction support and ACID.

Update frequency is low.

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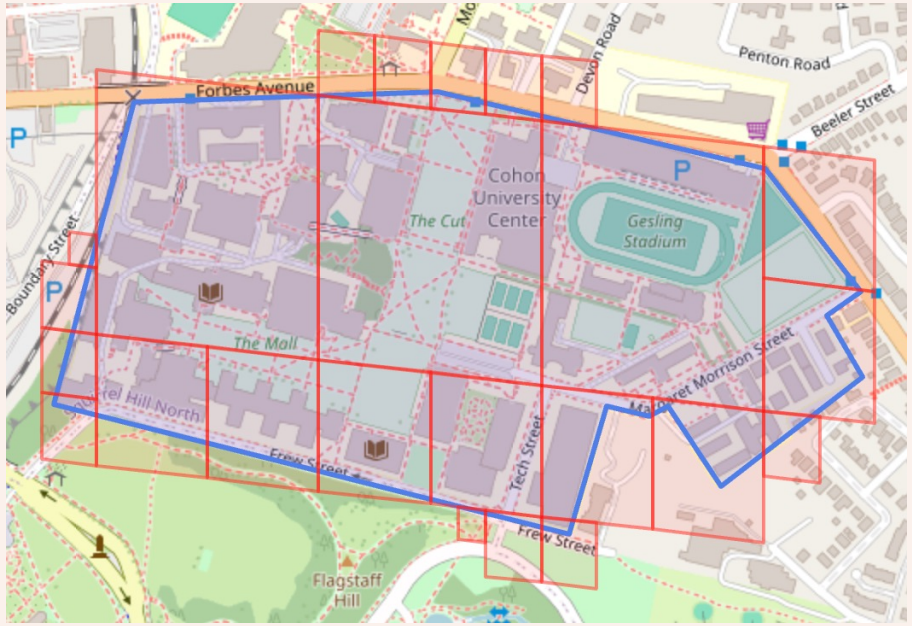

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Discovery queries are simple spatial lookups and do not need a full-fledged database.

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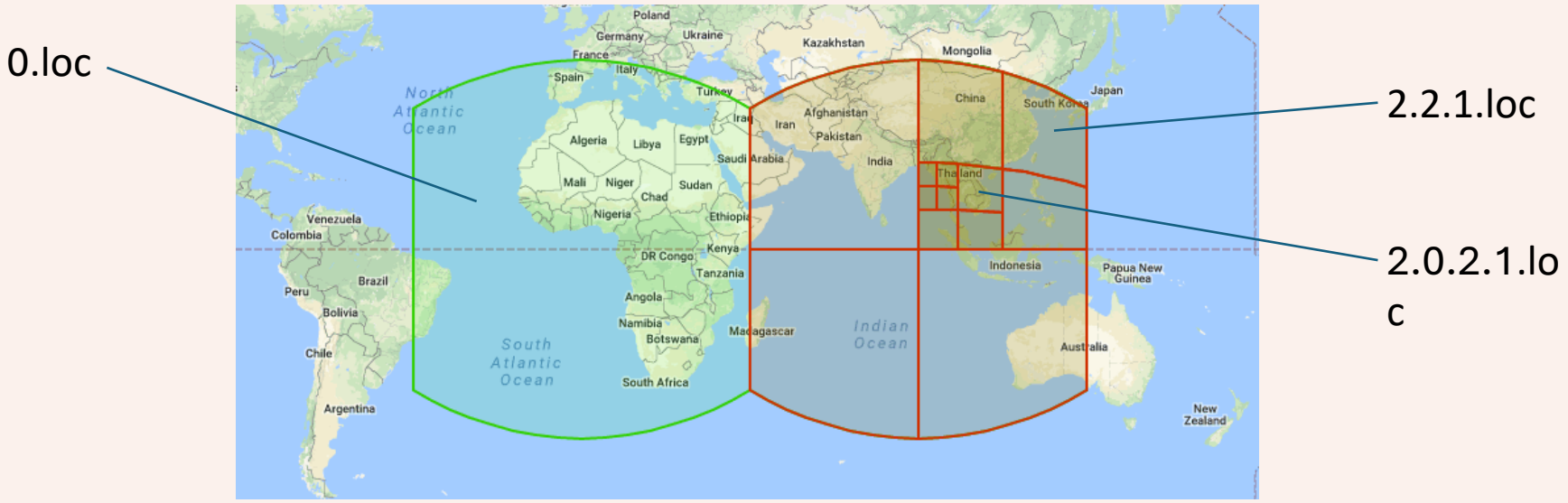
Update frequency is low.

The rate at which new maps are registered in the system is relatively low compared to the rate at which existing records are read.

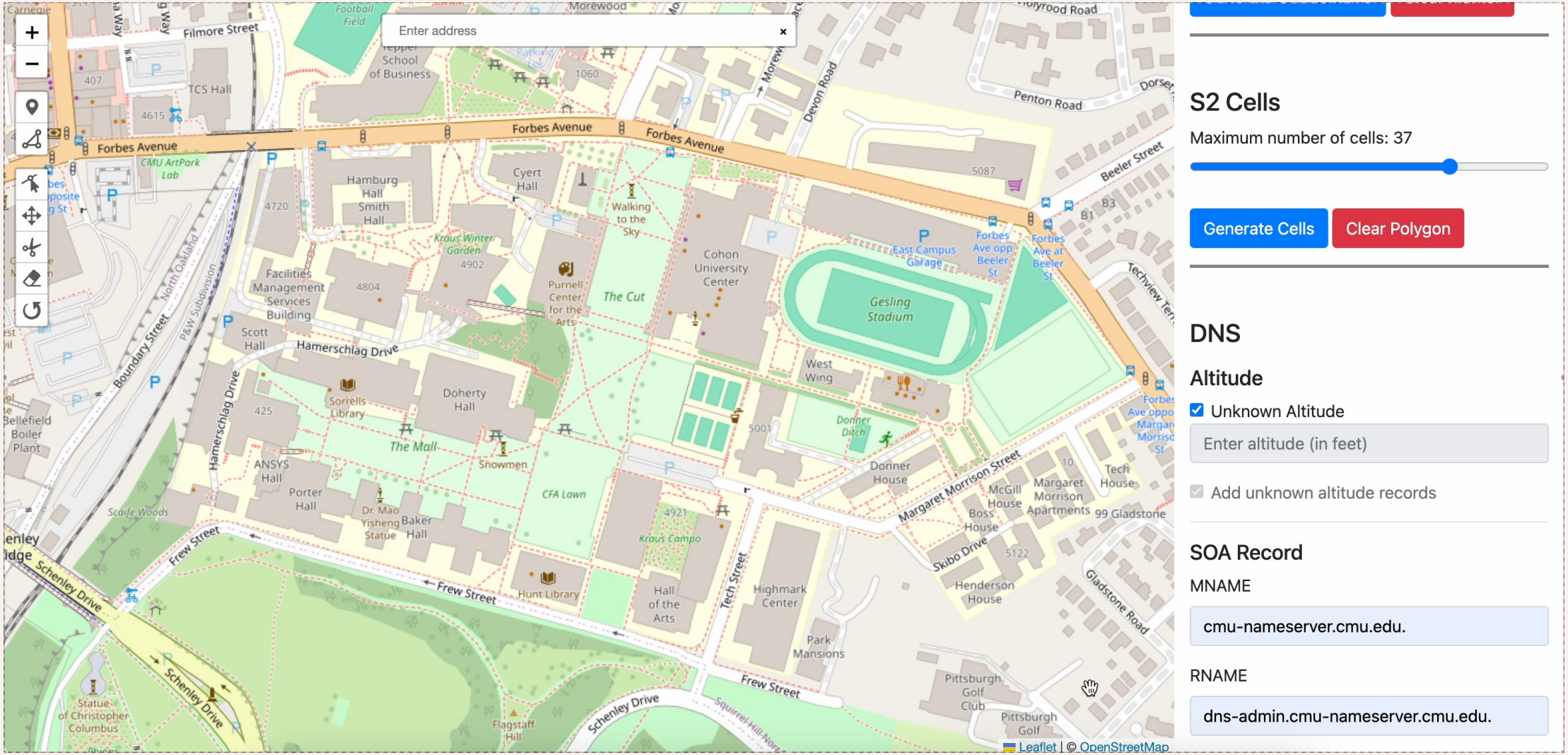
# Using DNS for spatial queries

Spatial indexing systems (e.g., S2, H3) divide the world into hierarchically organized primitive shapes.




- Each primitive shape can be represented by a domain name.
- Can leverage existing DNS infrastructure with modifications to the resolution process.

# Registering regions on the DNS



# Other Challenges

Ranking discovered Map Servers

Rearchitecting map-based services

Spatial Application design

Security and privacy implications

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Spatial Application design

Security and privacy implications

Which is better?

CMU

CMU Maps

Student Maps

# Other Challenges

Ranking discovered Map Servers

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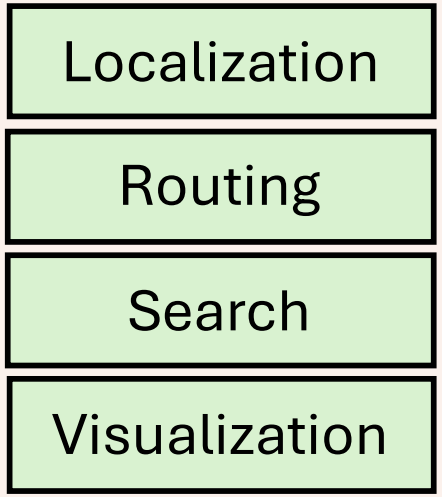
Security and privacy implications

How to implement services across client and map servers?



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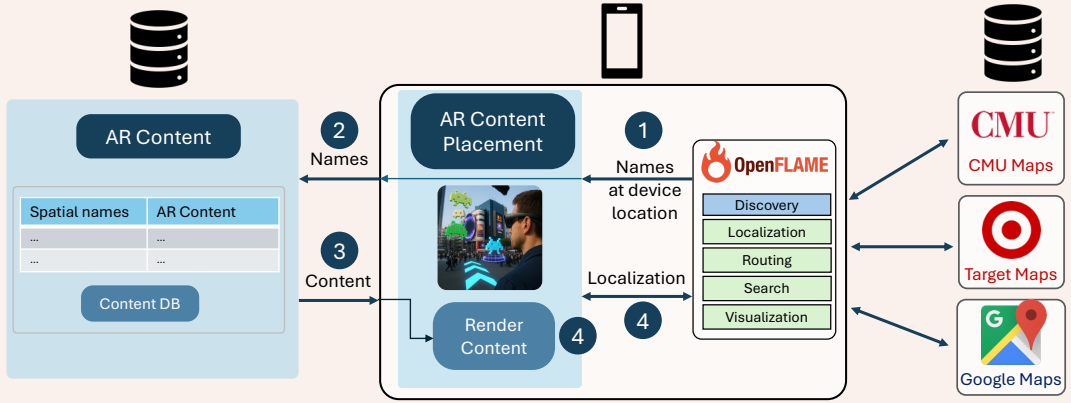
Common design principles across applications?



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What are the attack surfaces and how can we deal with them?

# To conclude…

Federated mapping is a new domain with multiple research challenges and huge  potential to unlock a new class of applications.

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