



Federated Maps to Enable the Spatial Web

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CMU



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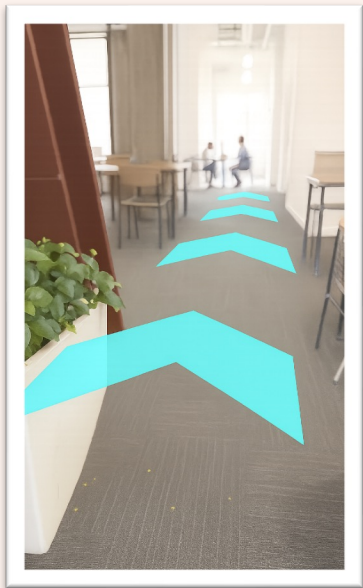


Anthony Rowe

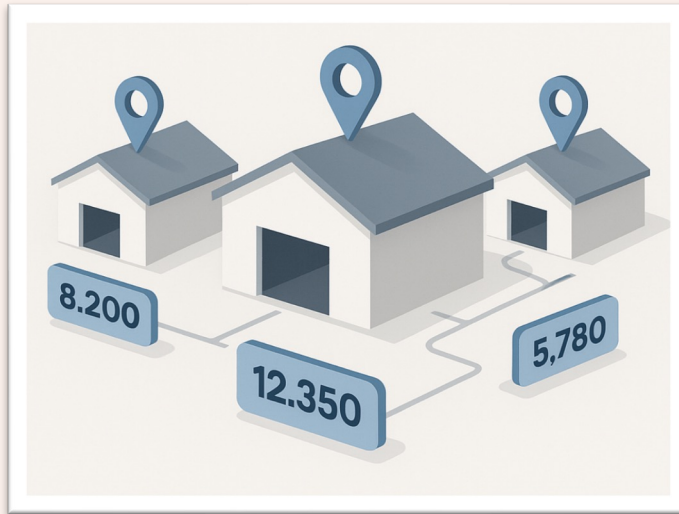


Srinivasan Seshan

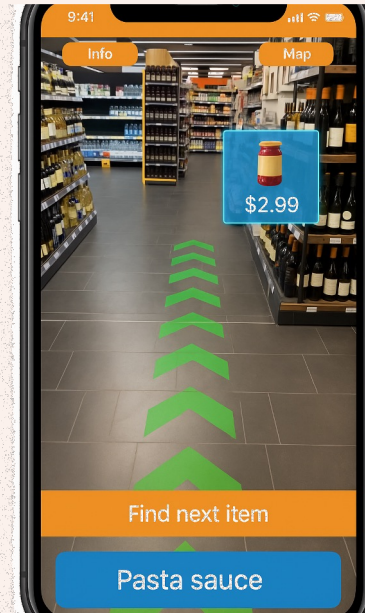
Examples of Spatial Applications



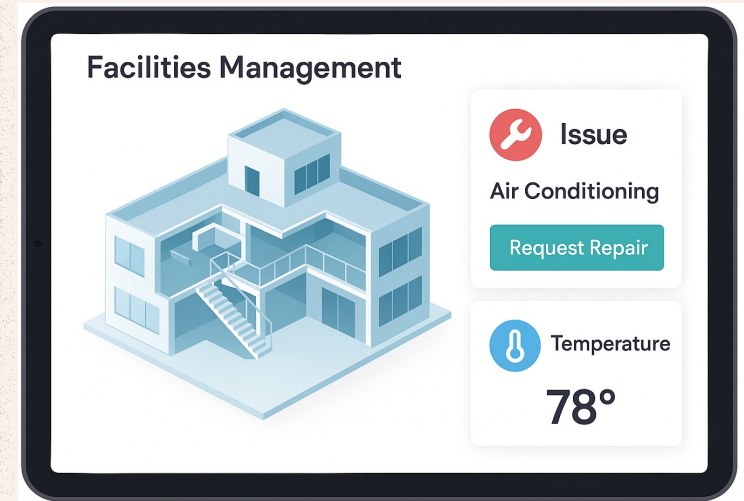
3D indoor
navigation



Inventory
management



AR shopping



Facilities
management

Examples of Spatial Applications



Fine-grained
location search



Placing AR content

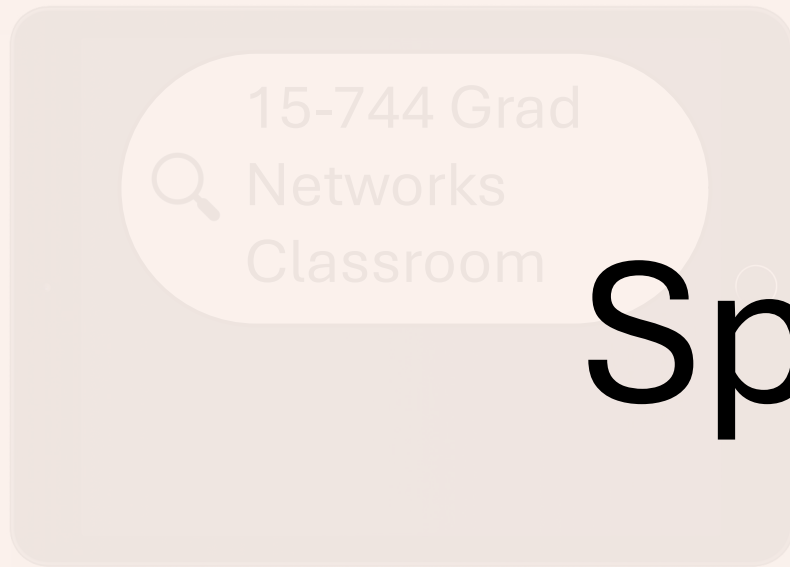


Autonomous Robots

Facilities
management

Examples of Spatial Applications

Spatial Web



Fine-grained
Indoor 3D location search
navigation inventory
management



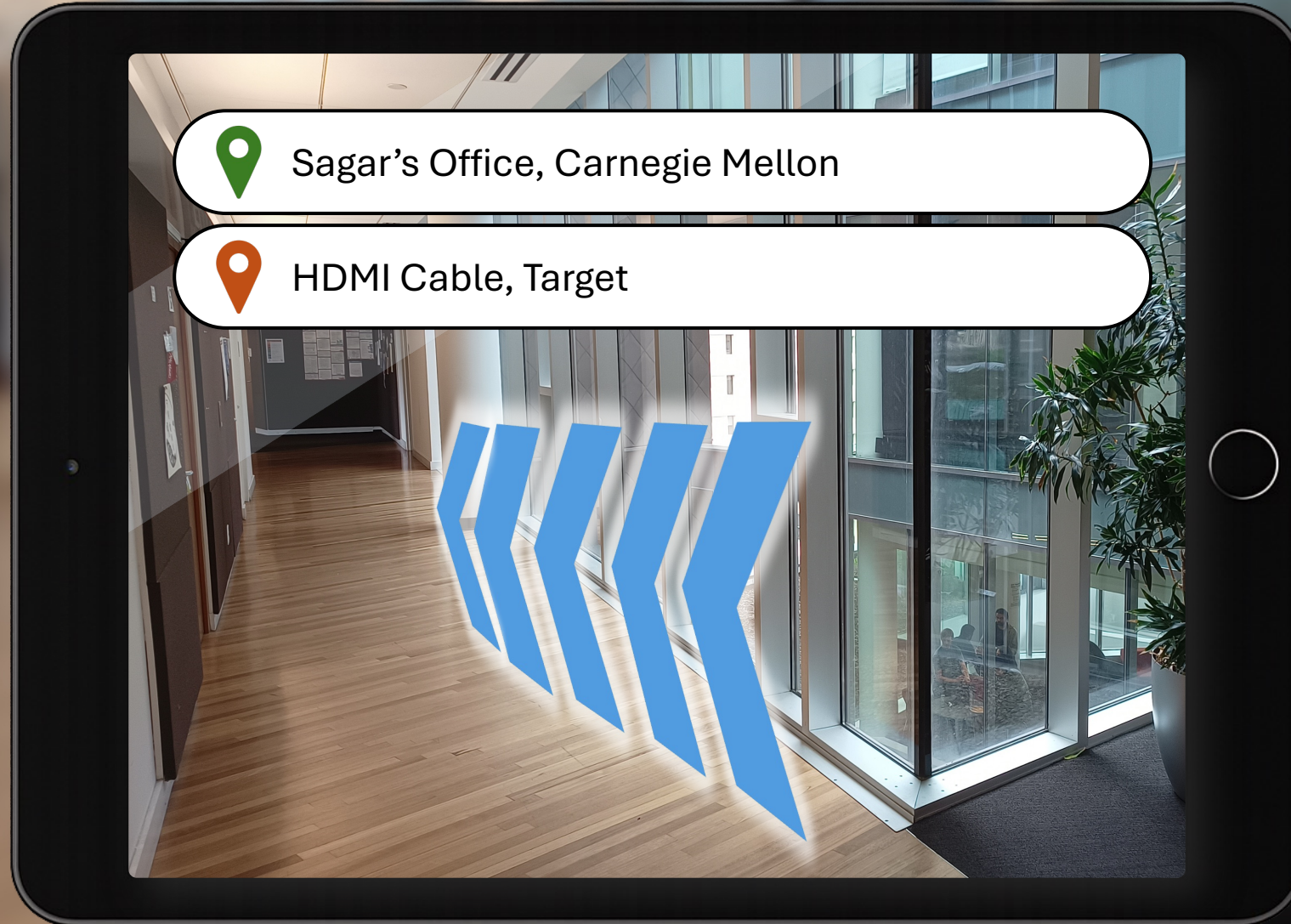
Placing AR content
AR shopping



Autonomous Robots
Facilities
management

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



Sagar's Office, Carnegie Mellon



HDMI Cable, Target

Today's maps answer only a part of the problem



Google Maps



Apple Maps



mapbox



OpenStreetMap

Example Application: Shopping Navigator

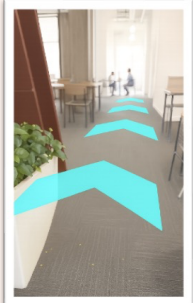


Sagar's Office, Carnegie Mellon

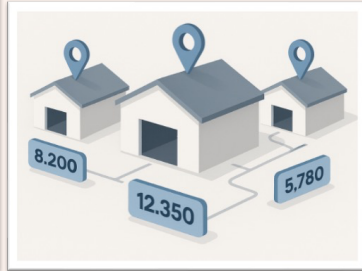


HDMI Cable, Target

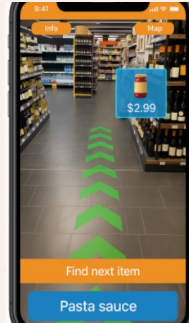




Indoor 3D
navigation



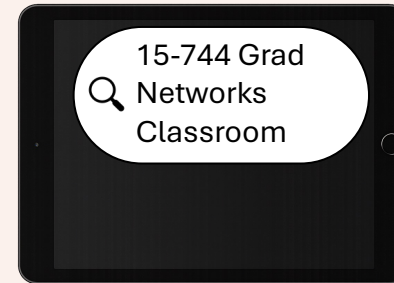
Inventory
management



AR shopping



Facilities
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Fine-grained
location search



Placing AR content



Autonomous Robots

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?

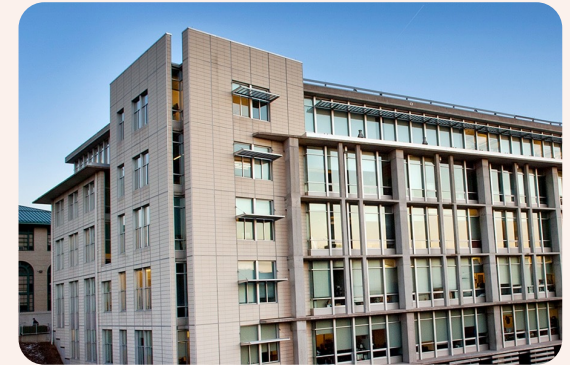
Indoor data collection is hard

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



Federation of Maps



target-maps.com

Federation of Maps



maps.cmu.edu



Federation of Maps



Federation of Maps



Federation of Maps



maps.cmu.edu



target-maps.com



maps.art.com



maps.google.com

Example Application: Shopping Navigator



Sagar's Office, Carnegie Mellon



Apple Pickup, Target



Example Application: Shopping Navigator



Sagar's Office, Carnegie Mellon



Apple Pickup, Target



Target Maps

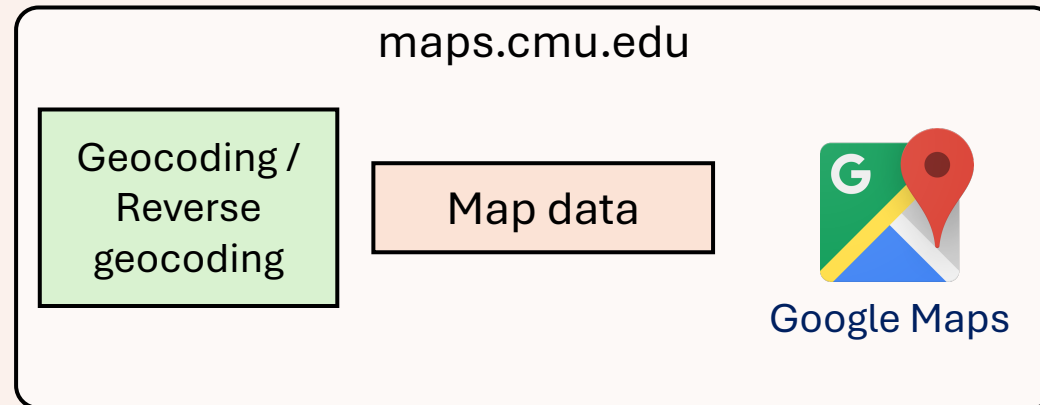
CMU

CMU Maps



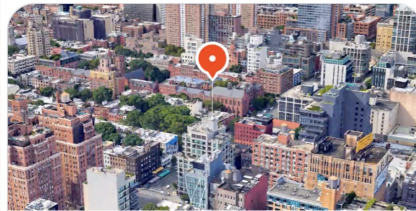
Google Maps

Design—a Centralized Spatial Naming System



Geocoding: Convert addresses to corresponding geographic coordinates.

Design—a Centralized Mapping Platform



Aerial View

PRO



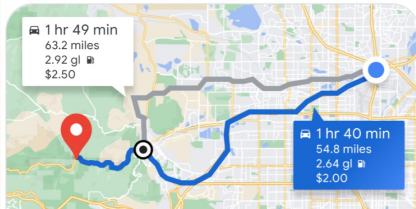
Dynamic Maps

ESSENTIALS



Elevation

PRO

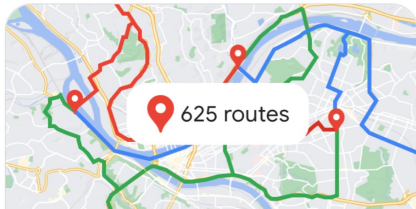


Compute Routes

ESSENTIALS

PRO

ENTERPRISE



Compute Routes Matrix

ESSENTIALS

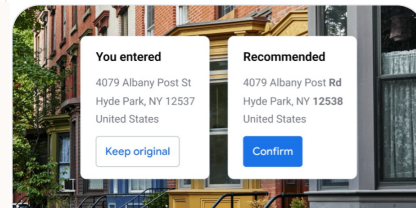
PRO

ENTERPRISE



Navigation SDK

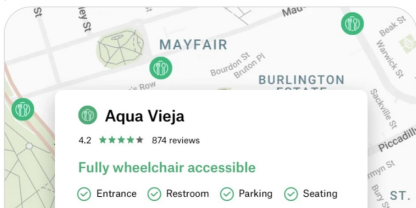
ENTERPRISE



Address Validation

PRO

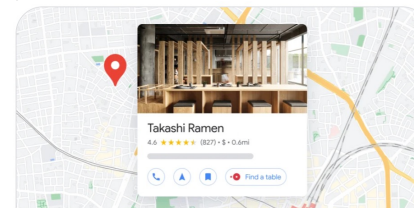
ENTERPRISE



Nearby Search

PRO

ENTERPRISE



Place Details

ESSENTIALS

PRO

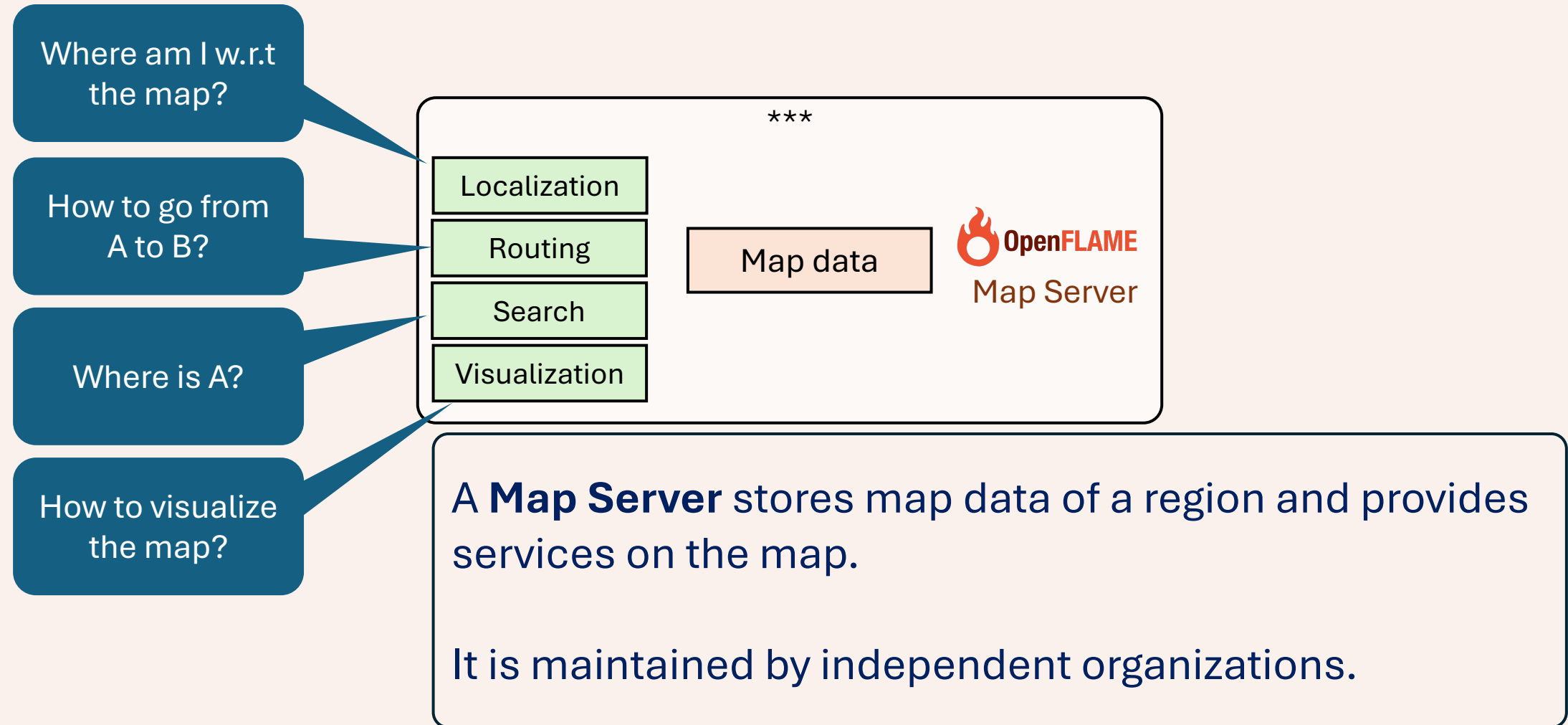
ENTERPRISE

Map data

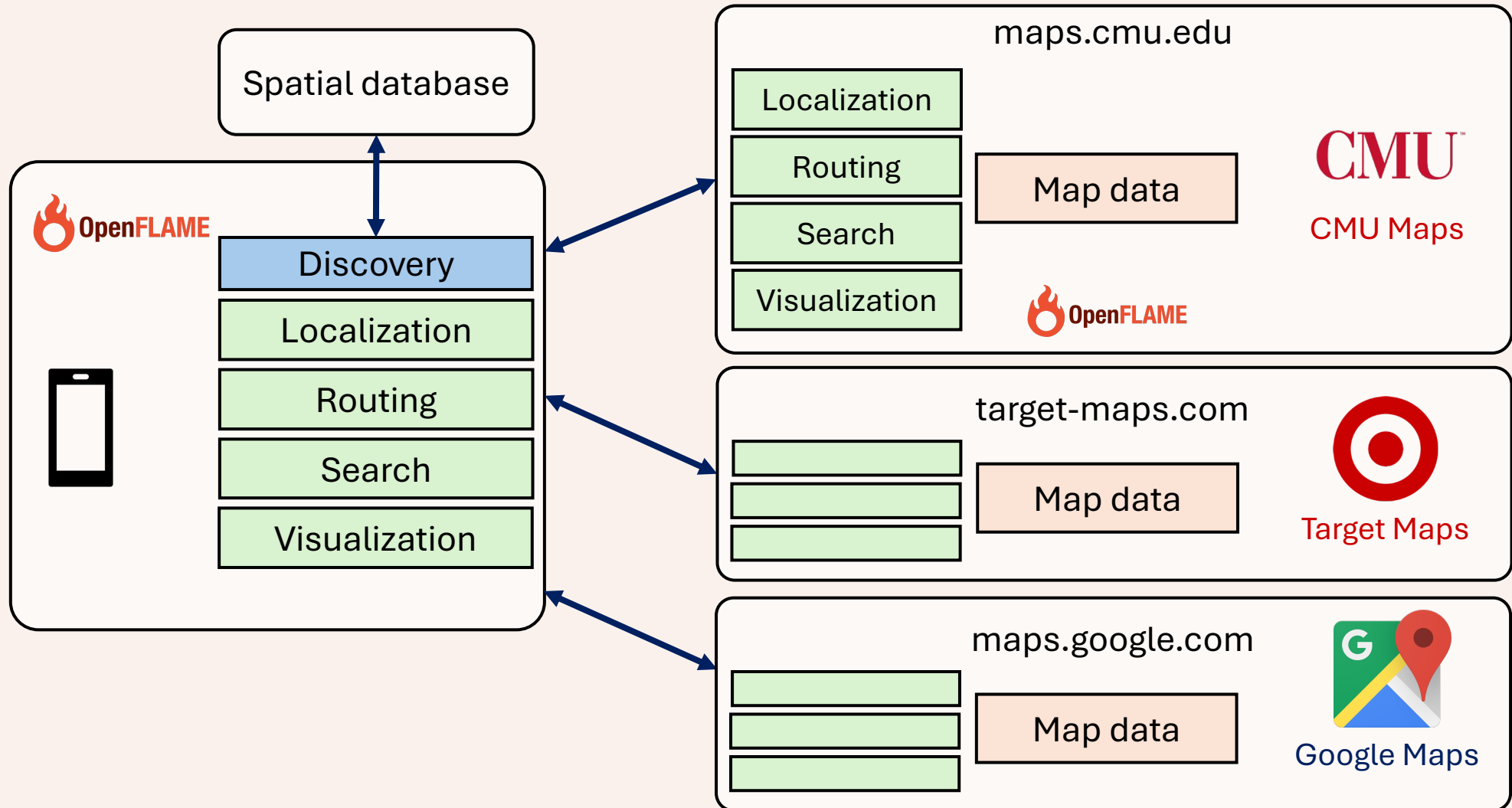


Google Maps

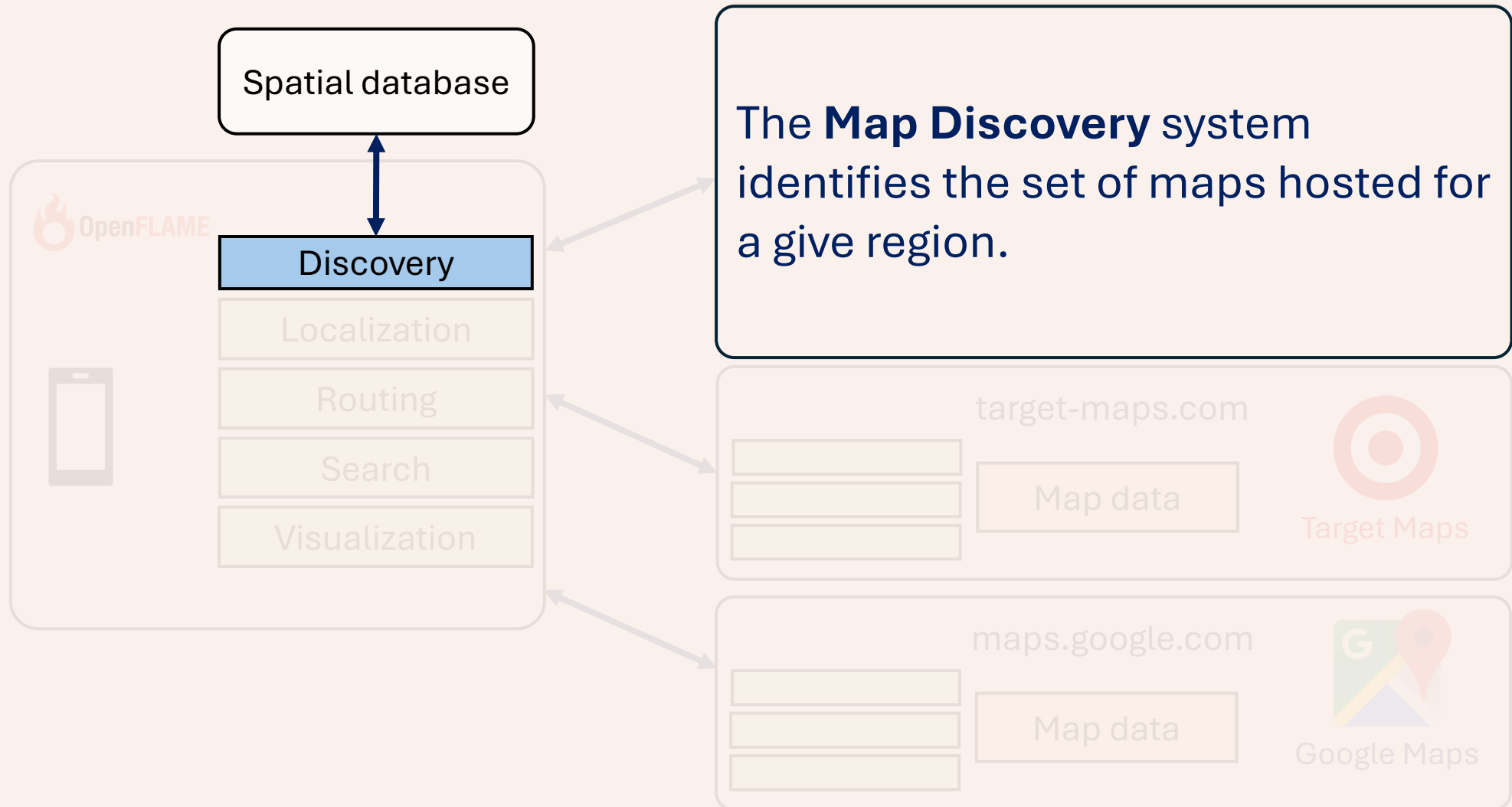
Design—OpenFLAME Map Server



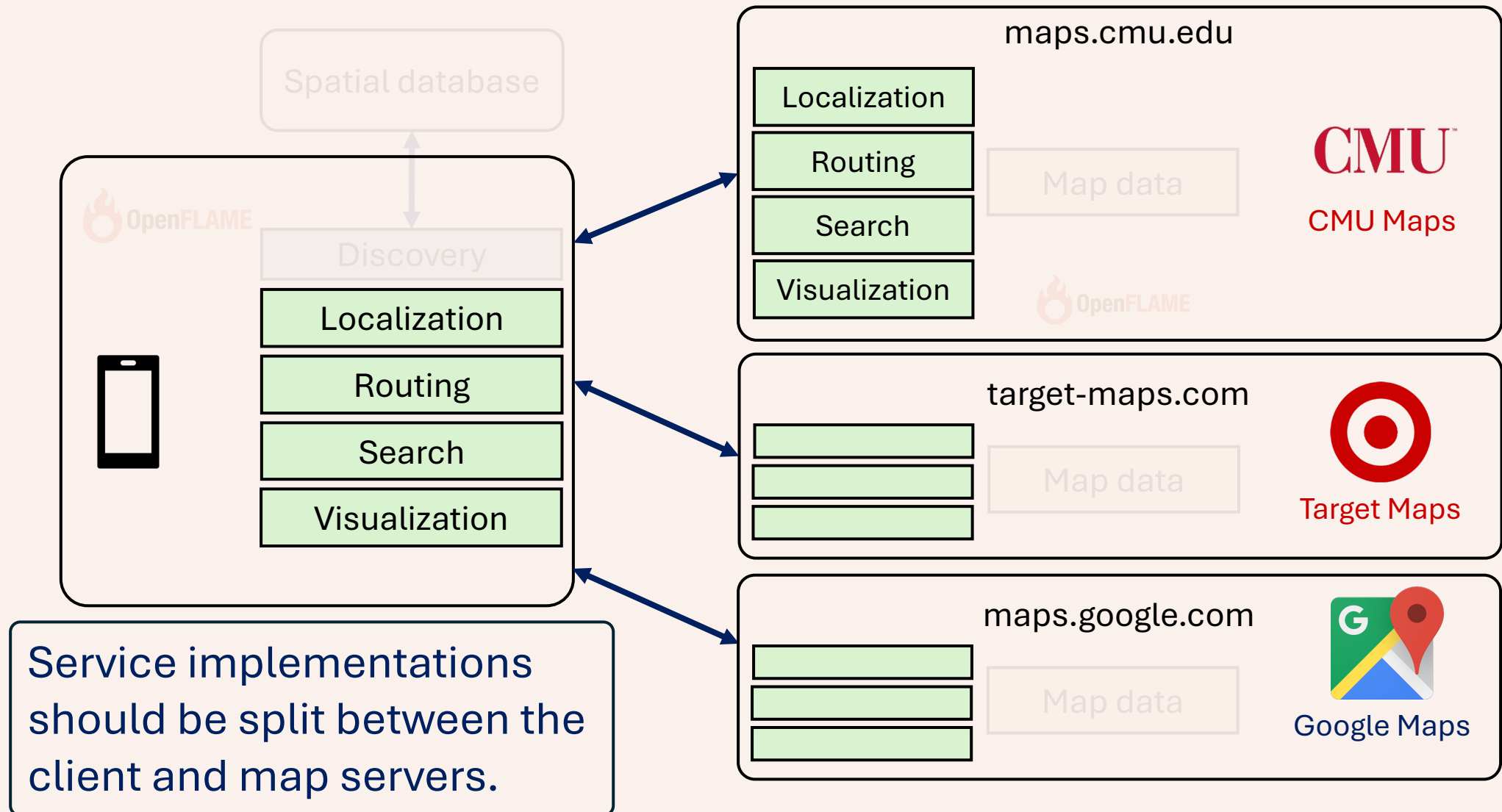
Design of OpenFLAME



Design—Map Discovery



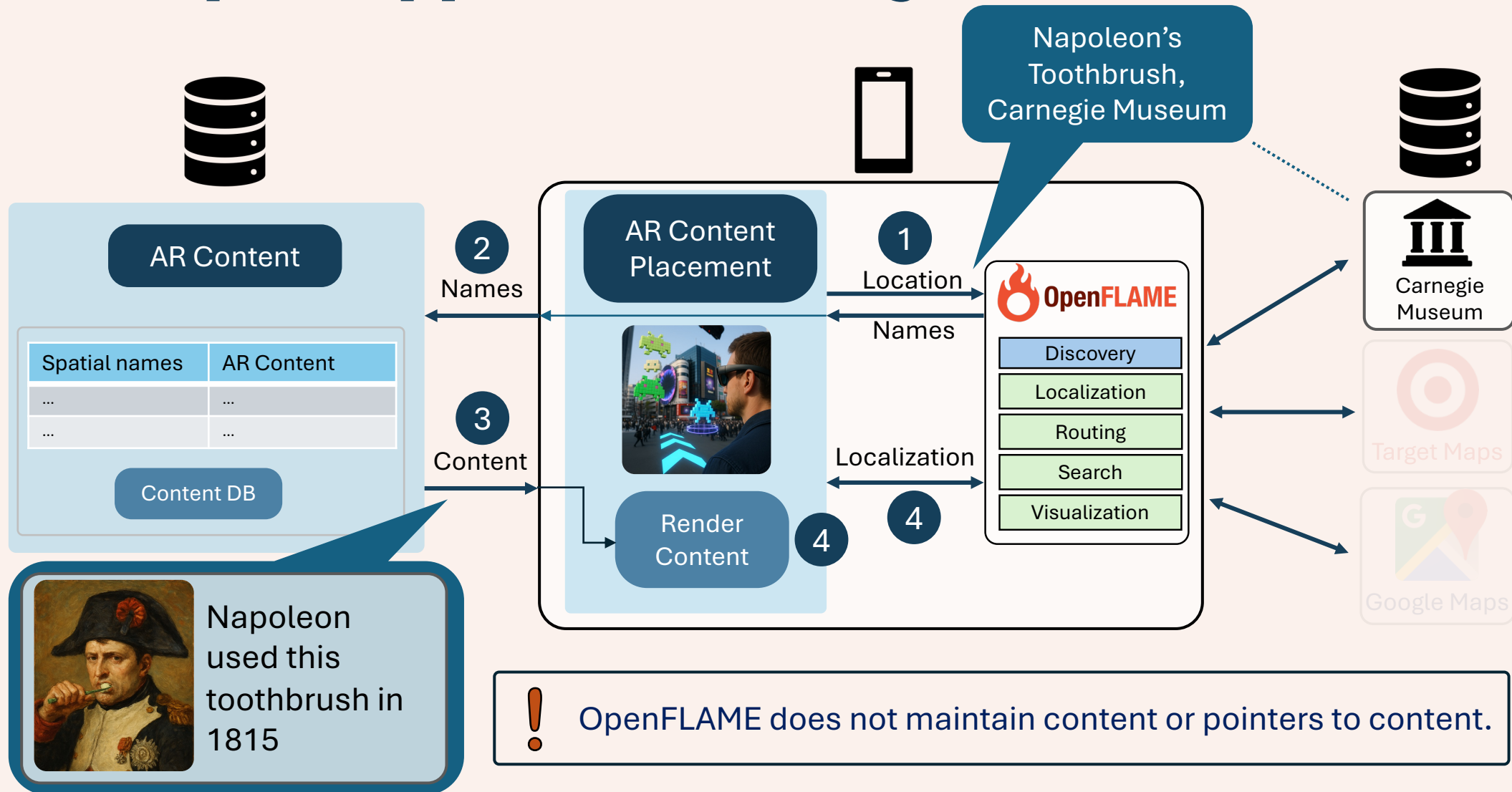
Design—Map-based Services



Example Application



Example: Application Design



Federation offers benefits

Privacy

Fine-grained access control

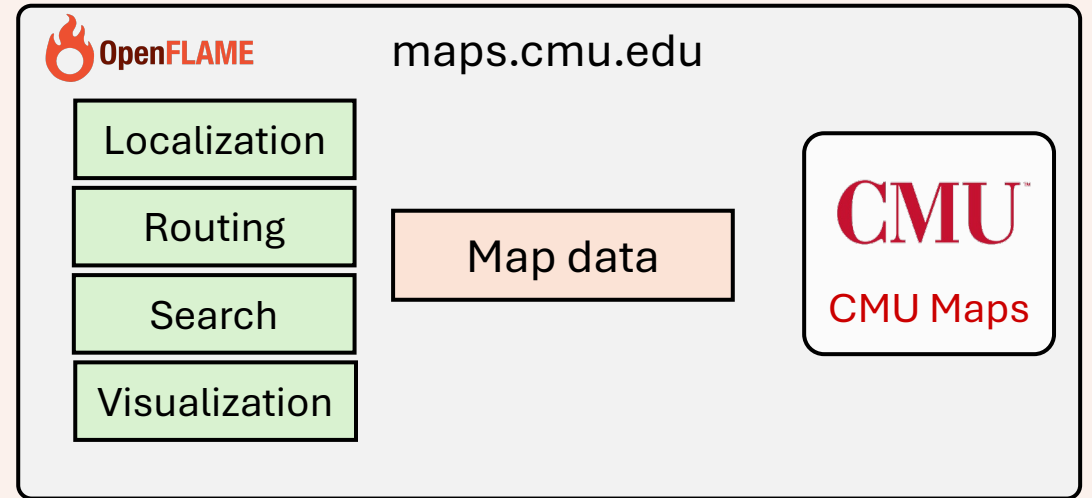
Independence of services

Federation offers benefits

Privacy

Fine-grained access control

Independence of services



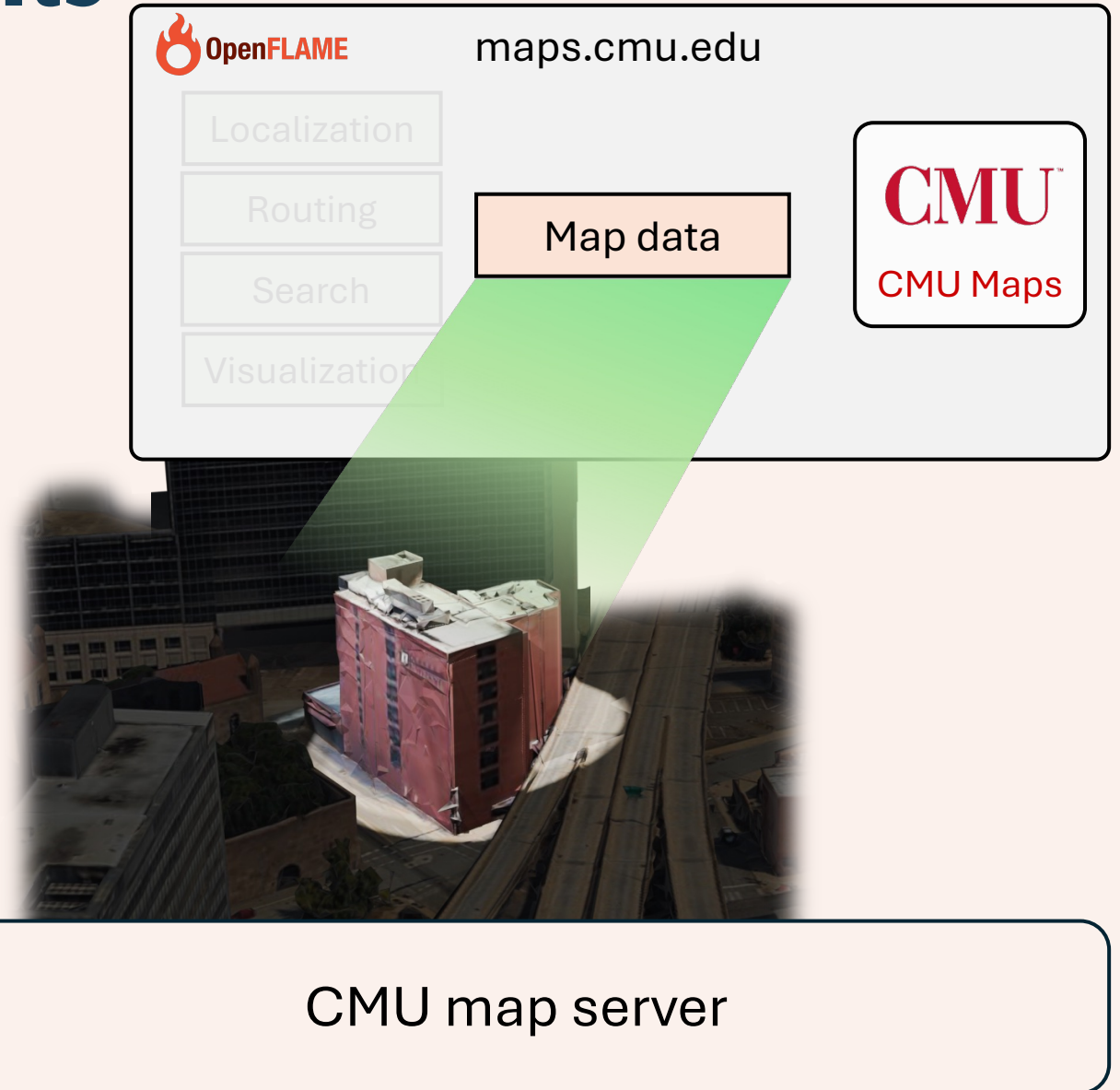
CMU map server

Federation offers benefits

Privacy

Fine-grained access control

Independence of services

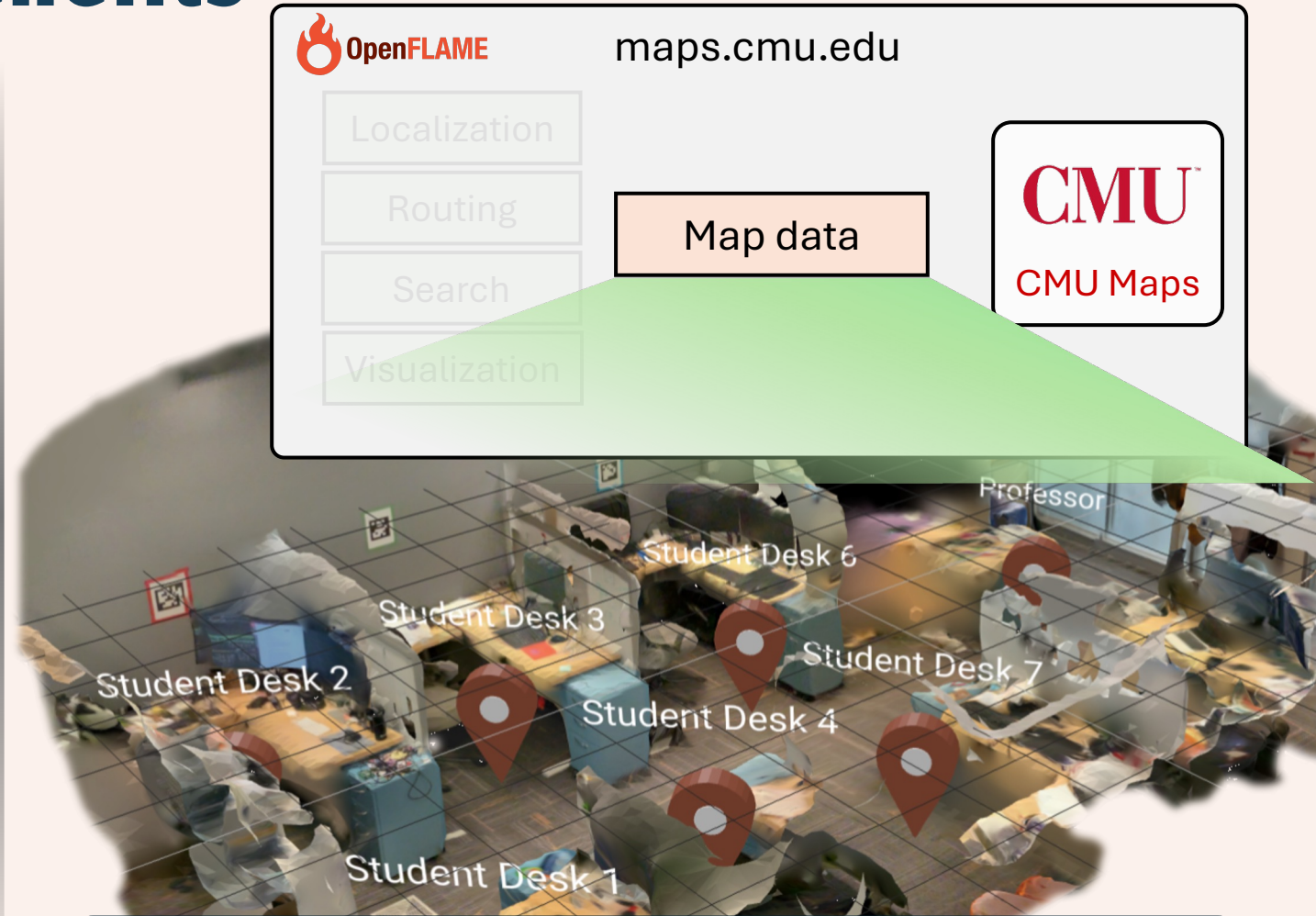


Federation offers benefits

Privacy

Fine-grained access control

Independence of services



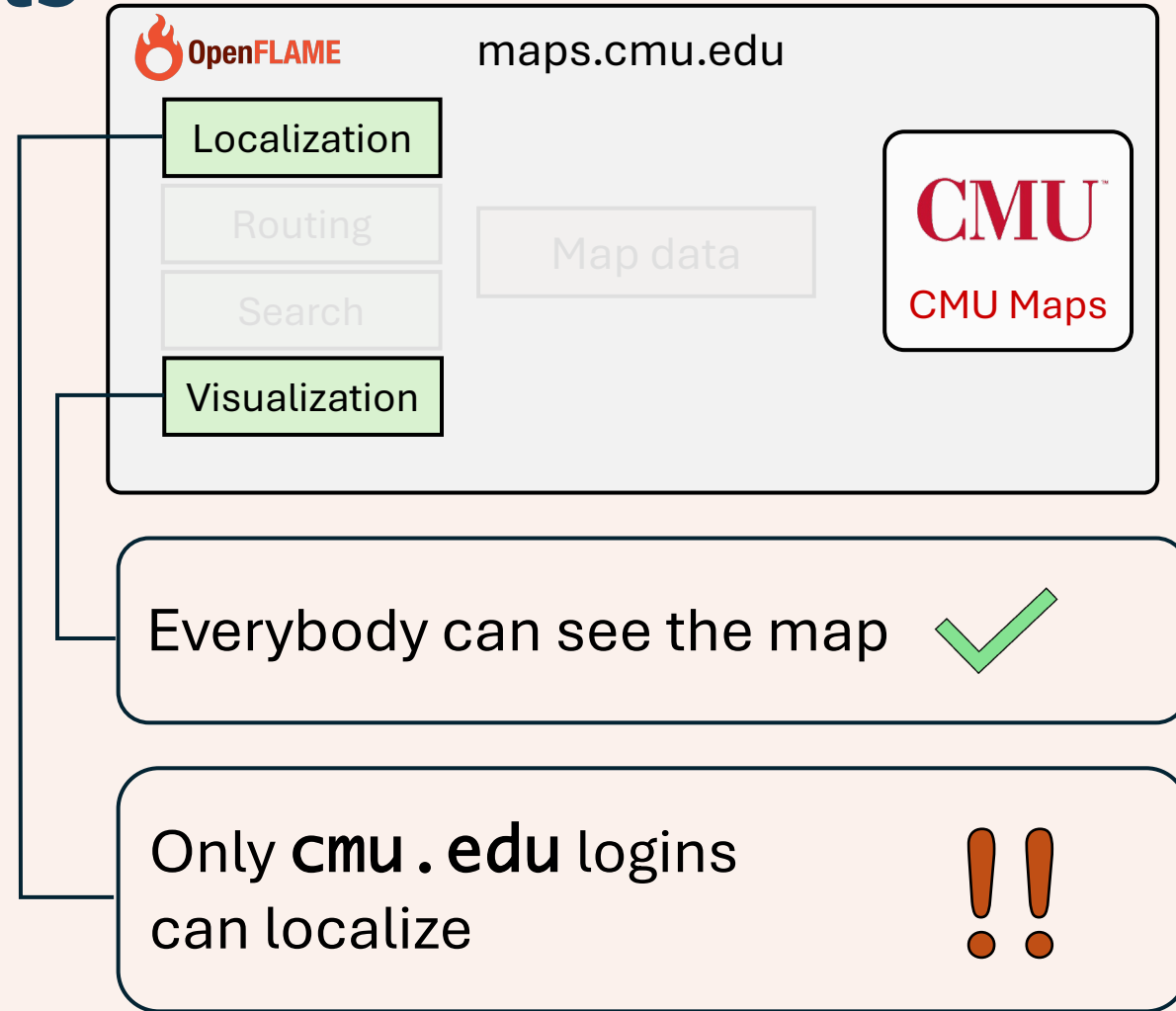
Private map data is stored on private servers.

Federation offers benefits

Privacy

Fine-grained access control

Independence of services



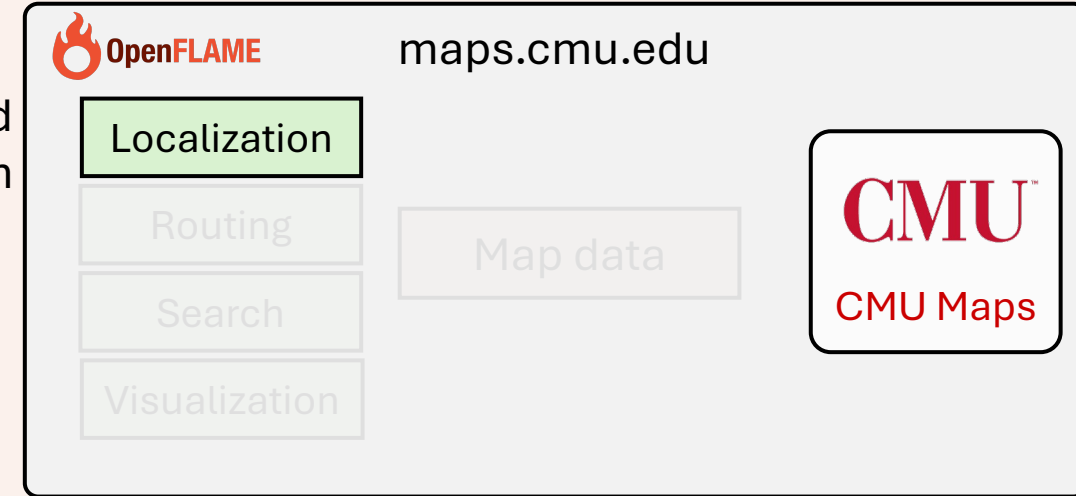
Federation offers benefits

Privacy

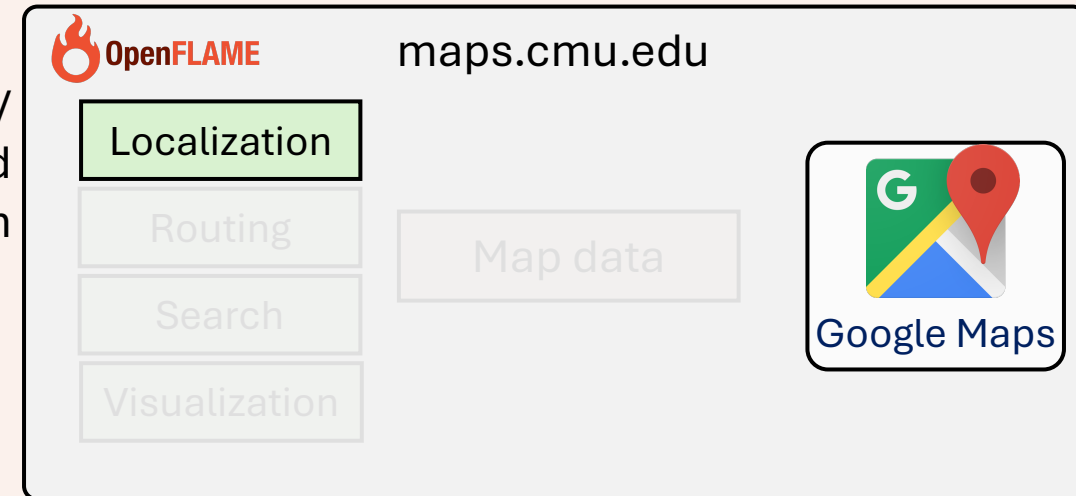
Fine-grained access control

Independence of services

Beacon-based
localization



GPS /
Image-based
localization



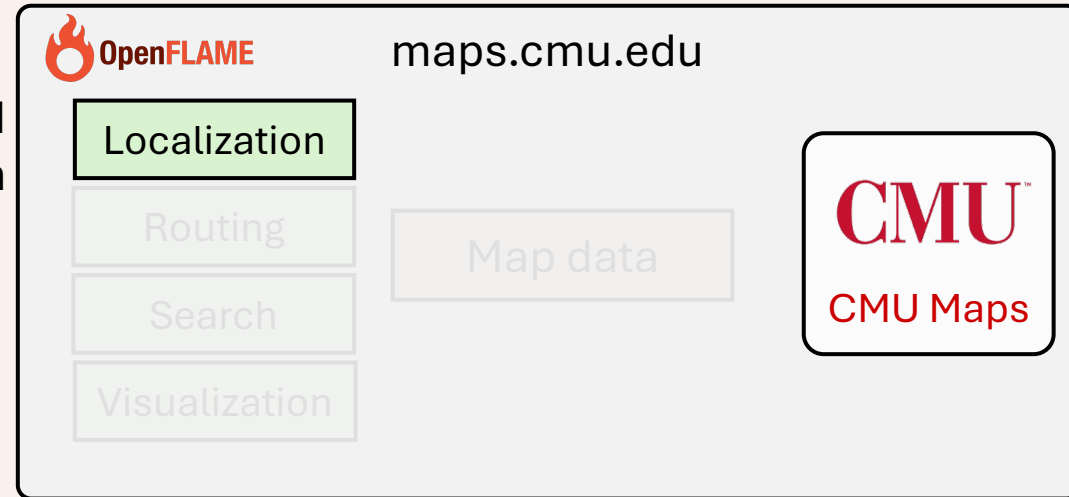
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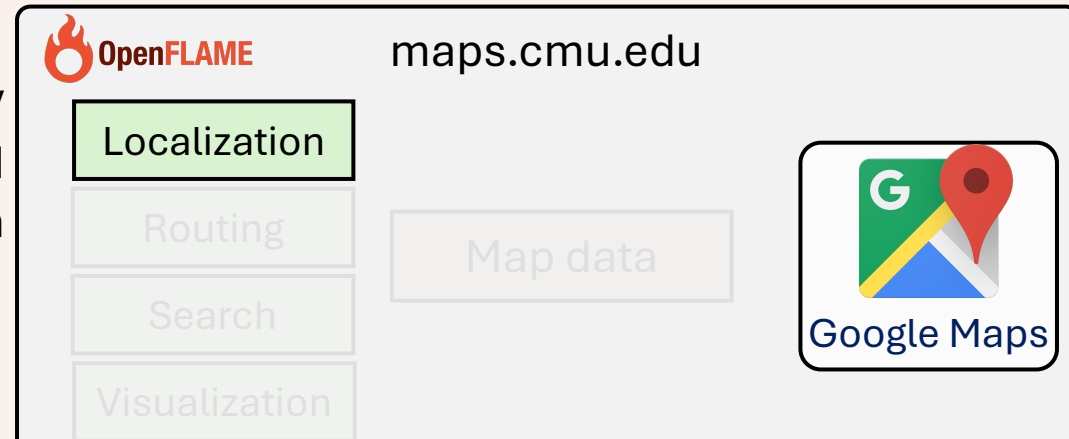
Fine-grained access control

Independence of services

Beacon-based
localization



GPS /
Image-based
localization



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

Challenges of Federation

Challenges of Federation

Design of map discovery

Ranking maps

Re-architecting services

Craig street, Pittsburgh

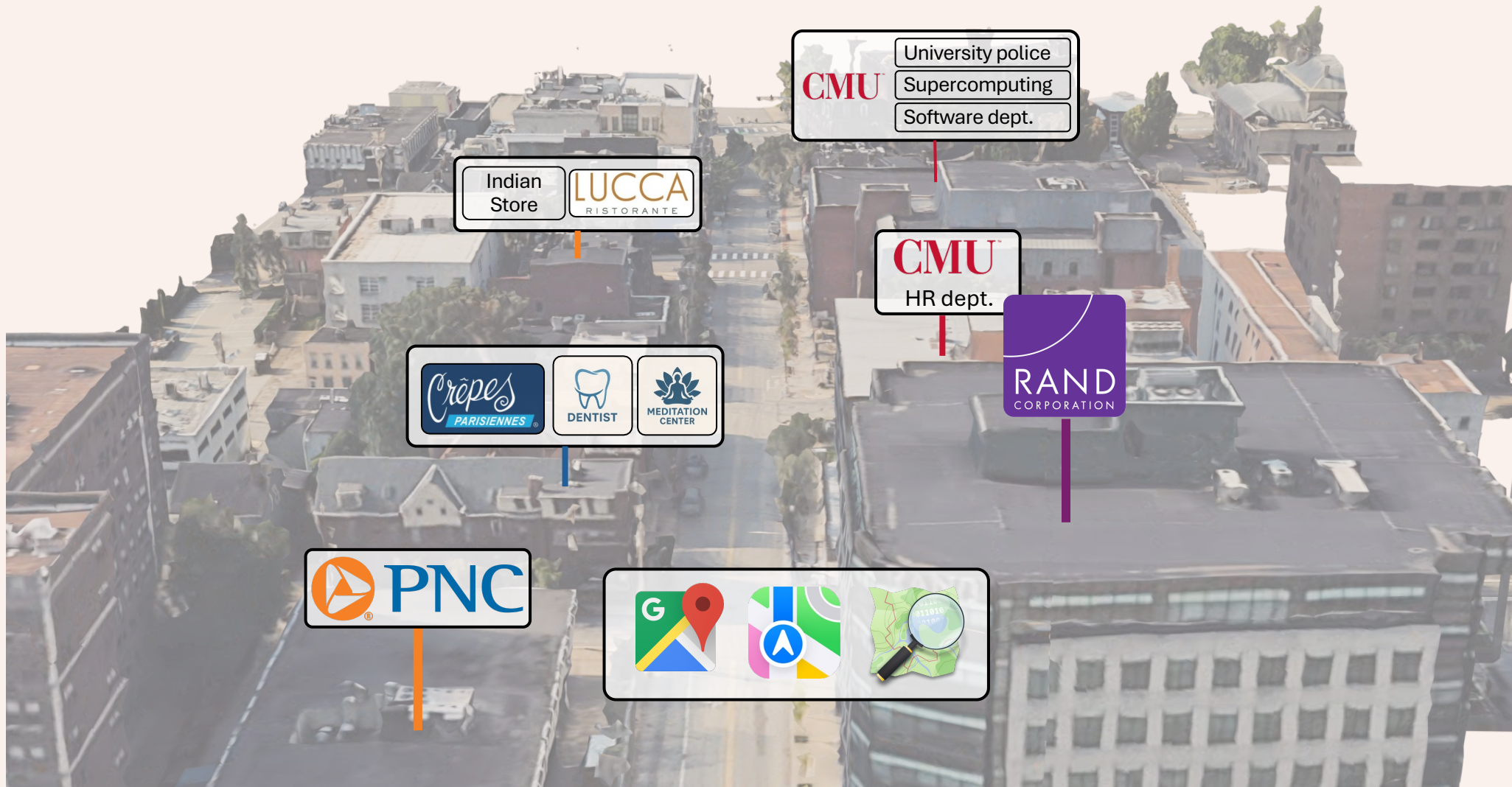


How do we discover all maps on this street?

Challenges—Map Discovery



Challenges—Map Discovery



Challenges—Map Discovery

It is a large-scale problem

Map boundaries are not clear-cut

Needs a universally trusted infrastructure

CMU

University police

Supercomputing

Software dept.

JCCA
RISTORANTE

CMU

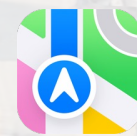
HR dept.

ARTIST

MEDITATION
CENTER

RAND
CORPORATION

PNC



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.

Reusing existing trusted infrastructure—DNS

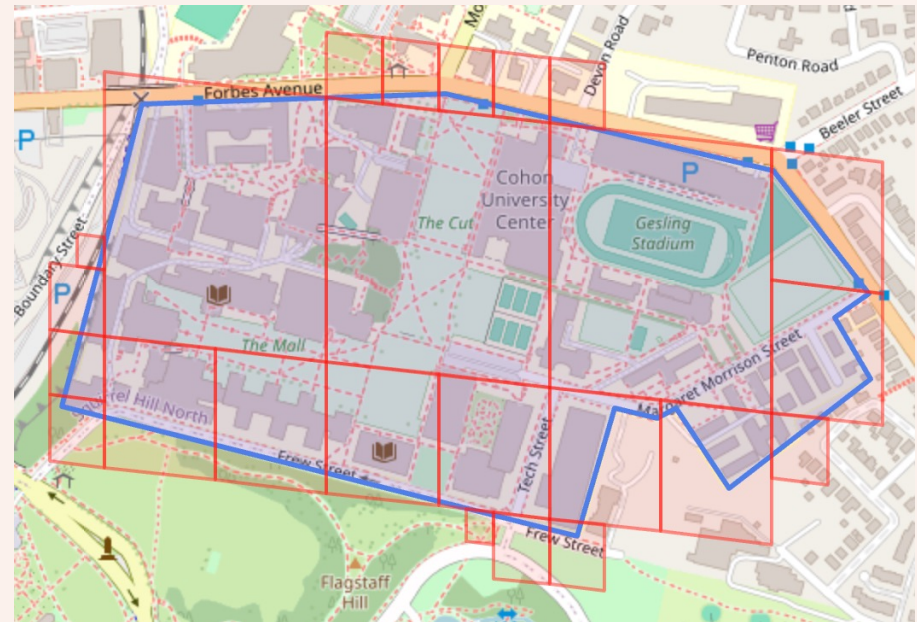
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Reusing existing trusted infrastructure—DNS

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We can use DNS as:

Map boundaries are fuzzy.

Discovery queries do not need transaction support and ACID.

Update frequency is low.

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

Reusing existing trusted infrastructure—DNS

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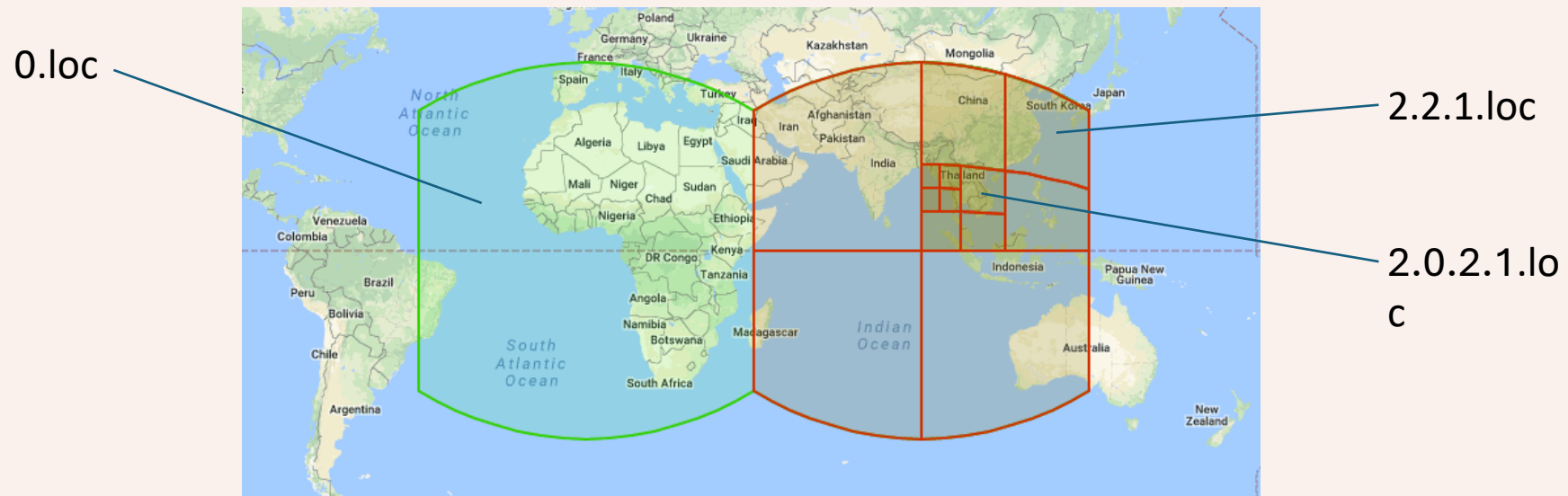
Discovery queries do not need transaction support and ACID.

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

Enter address

Forbes Avenue

Forbes Avenue

Forbes Avenue

Hamburg Hall

Smith Hall

Cyert Hall

Krous Winter Garden

4902

Purnell Center for the Arts

The Cut

Cohon University Center

Gesling Stadium

East Campus Garage

Forbes Ave opp Beeler St

Forbes Ave at Beeler St

Beeler Street

Boundary Street

Hamerschlag Drive

Scott Hall

Facilities Management Services Building

4804

Doherty Hall

Sorrells Library

425

ANSYS Hall

Porter Hall

Dr. Mao Yisheng Baker Statue Hall

The Mall

Snowmen

CFA Lawn

Hunt Library

4921

Kraus Campo

Hall of the Arts

West Wing

Donner House

Donner Ditch

Margaret Morrison Street

McGill House

Boss House

5122

Henderson House

Gladstone Road

Schenley Drive

Frew Street

Schenley Drive

Schenley Drive

Statue of Christopher Columbus

Flagstaff Hill

Pittsburgh Golf Club

Pittsburgh Golf

Leaflet | © OpenStreetMap

S2 Cells

Maximum number of cells: 37

Generate Cells Clear Polygon

DNS

Altitude

☒ Unknown Altitude

Enter altitude (in feet)

☒ Add unknown altitude records

SOA Record

MNAME

cmu-nameserver.cmu.edu.

RNAME

dns-admin.cmu-nameserver.cmu.edu.

Other Challenges

Ranking discovered Map Servers

Rearchitecting map-based services

Spatial Application design

Security and privacy implications

Other Challenges

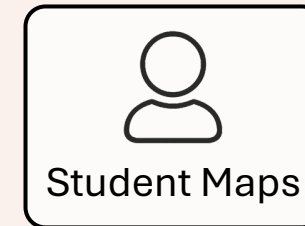
Ranking discovered Map Servers

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Security and privacy implications

Which is better?



Other Challenges

Ranking discovered Map Servers

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Spatial Application design

Security and privacy implications

How to implement services
across client and map servers?

Localization

Routing

Search

Visualization

Other Challenges

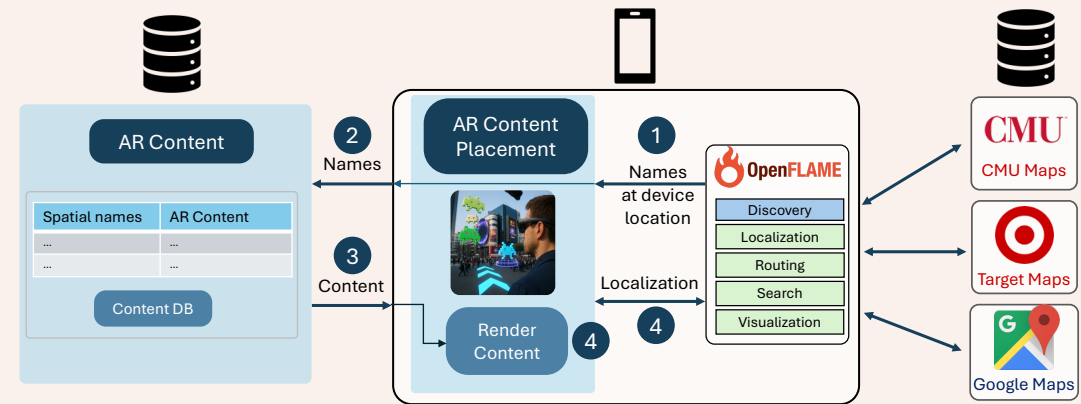
Ranking discovered Map Servers

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Security and privacy implications

Common design principles
across applications?



Other Challenges

Ranking discovered Map Servers

Rearchitecting map-based services

Spatial Application design

Security and privacy implications

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.



Open**FLAME**

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