A Constraint Satisfaction Approach to Geospatial Reasoning

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Outline

- Goals and Motivation
- Problem Solving Approach
- Constraint Formulation
- Experimental Results
- Discussion and Future Work

Goals

- Identify buildings in satellite imagery
  - Infer as much information as possible
  - Accurate identification
- Fuse diverse information sources
  - High resolution imagery
  - Vector data
  - Online data sources

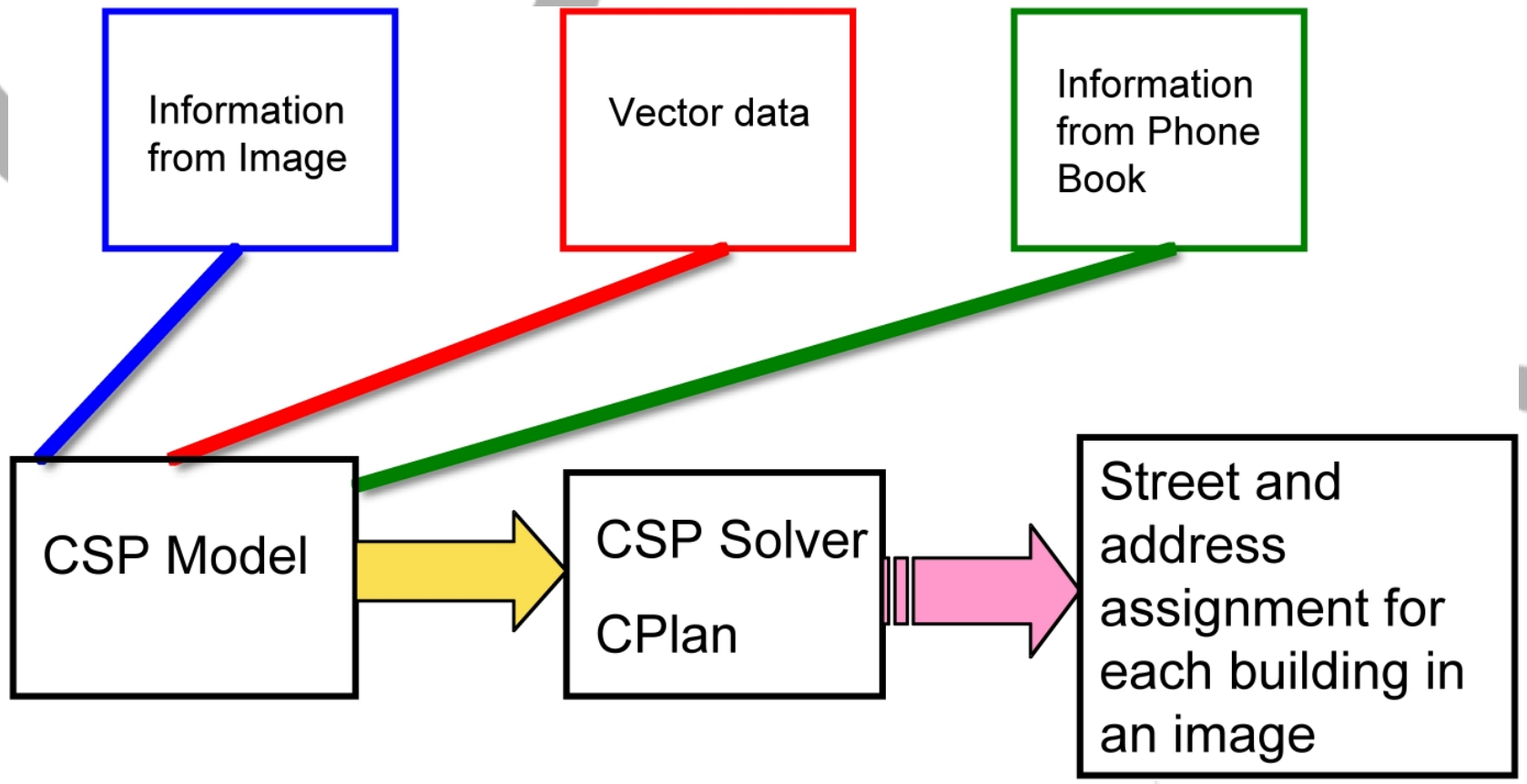
Motivating Example

- Chinese Embassy Bombing in Belgrade (1999)
- From Pickering Report
  - Flawed procedure to identify the geographic coordinates of FDSP used
  - Chinese Embassy was not in DB therefore was not considered
  - But Chinese Embassy was in phone book

Available information

- High Resolution Satellite Imagery
  - Detect buildings
- NGA vector data
  - Locate streets on satellite imagery
- White and Yellow Pages for Belgrade
  - Find all information about buildings for a given street

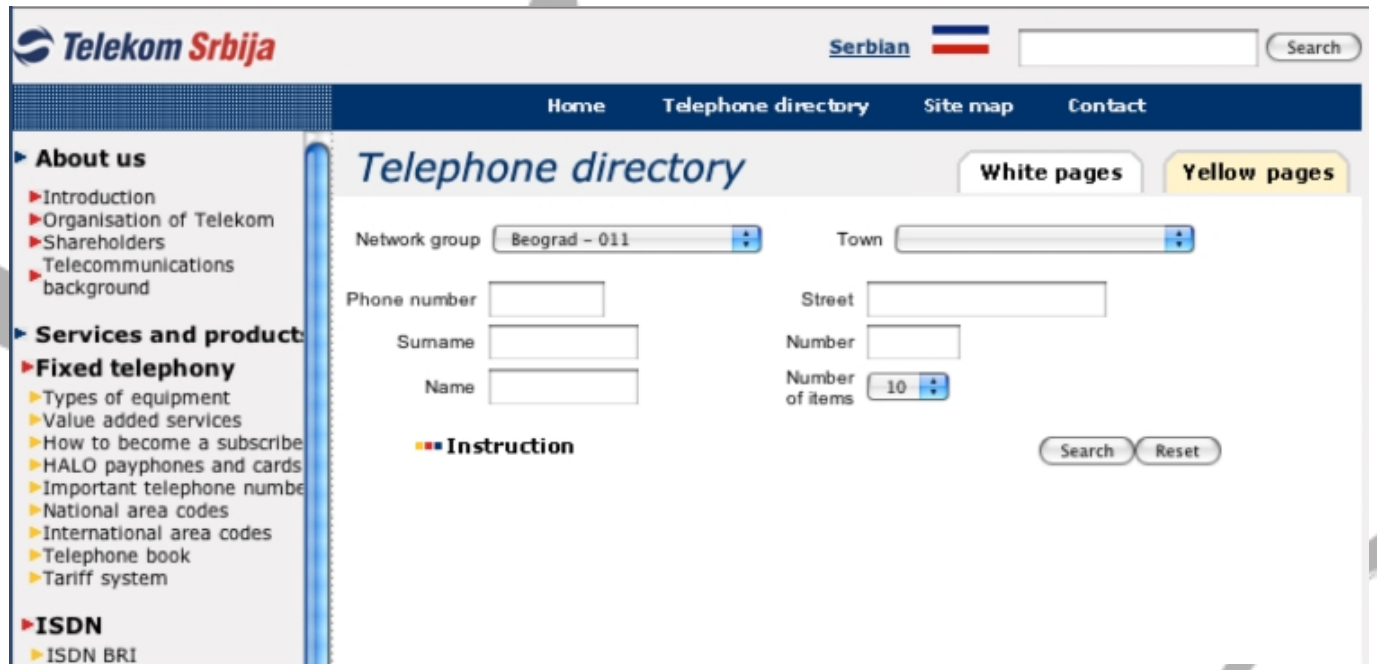
Problem Solving Approach



Source Information

- Set of street names
- Set of buildings
  - Potential street(s) it is on
  - Side of street it is on
  - Order for a given street
- Additional information
  - Side of street where even numbers lie
  - Ascending addresses direction
- Helpful but not required
  - Constrains the problem

Source Information



Phone book

- Set of known addresses for all streets in image (vector data)

Key Ideas

- Use both explicit and implicit information in publicly available data sources.
  - Challenge: combining this information
  - Solution: use a constraint satisfaction framework
- Leverage common properties of streets and addresses
  - Cannot be deduced from any individual source but require the combination of data from multiple sources.

Assumptions Made

- Buildings in imagery are identified
- Each building is made an assignment
- Multiple assignments per building possible
- Sources are accurate but not necessarily complete

Constraint Formulation

- Variables (m = number of buildings)
  - $s_1 \ldots s_m$ = {streets in image}
  - $\#_1 \ldots \#_m$ = {set of natural numbers}
  - e_{ew} = {N,S}, e_{ns} = {W, E}
  - a_{ew} = {W, E}, a_{ns} = {N,S}

Constraint Formulation

- 4 constraints
  - Even or ¬Even (Odd) numbering constraint
  - Ordering constraint
  - Phone book constraint
  - Global Variables Set constraint
    - Implementation detail

Even or ¬Even Constraint

Assures all these buildings will be even or odd, not a mix

Ordering Constraint

Assures that address > address because we know numbers ascend in south direction on N/S running streets

Phone Book constraint

Street A

Assures that all of the odd #s and the even #s for Street A (as found in the phone book) are a subset of the solution returned

Example

Street T
- TRESNJIN CVET

Street U
- BULEVAR UMETNOSTI

Street A
– BULEVAR AVNOJA

Street M
- BULEVAR MIHAILA PUPINA

Example

Phone Book:

Nothing on T

1,2,3,5,7,9 on U

1 on A

Street T
- TRESNJIN CVET

Street U
- BULEVAR UMETNOSTI

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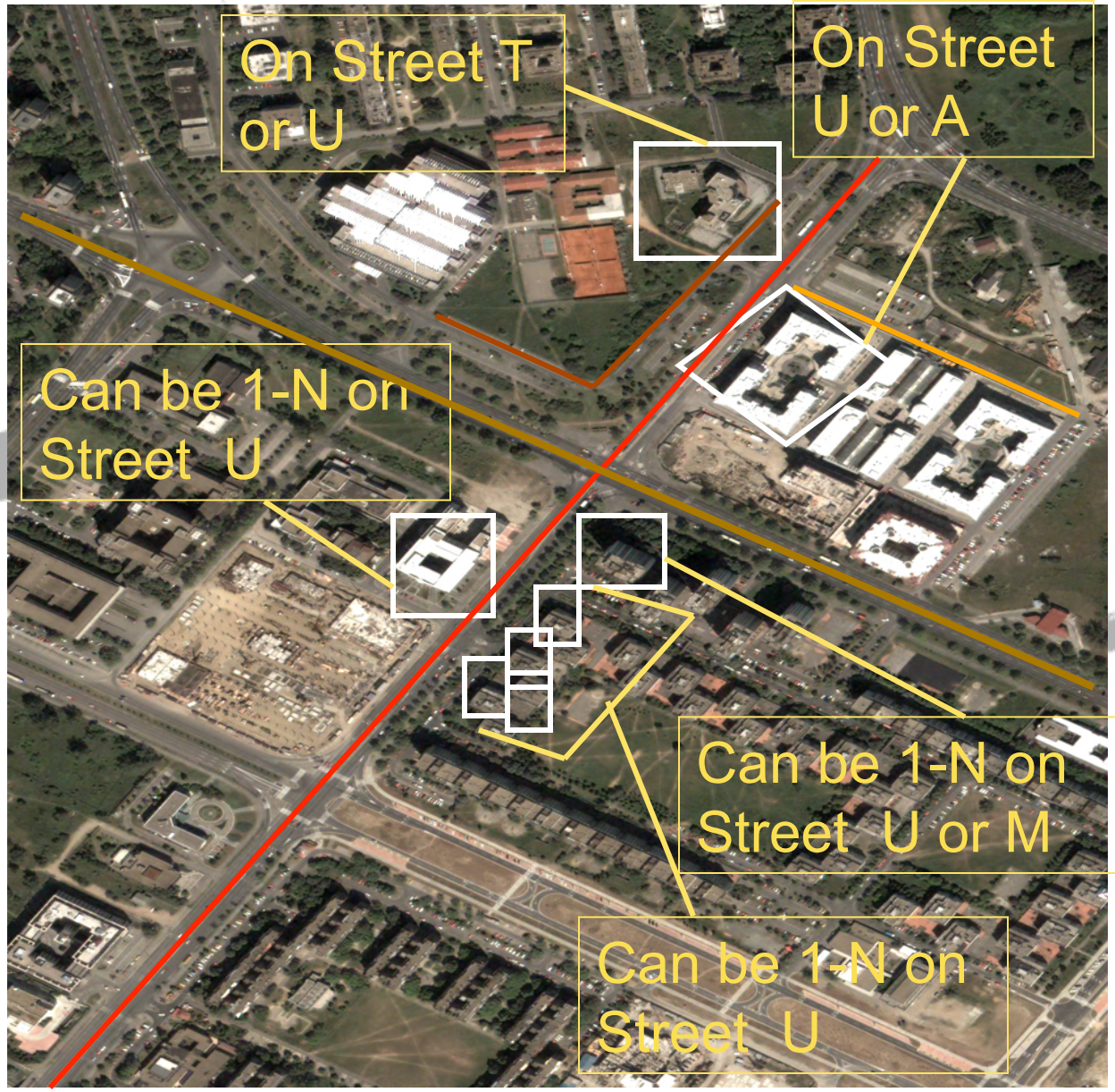

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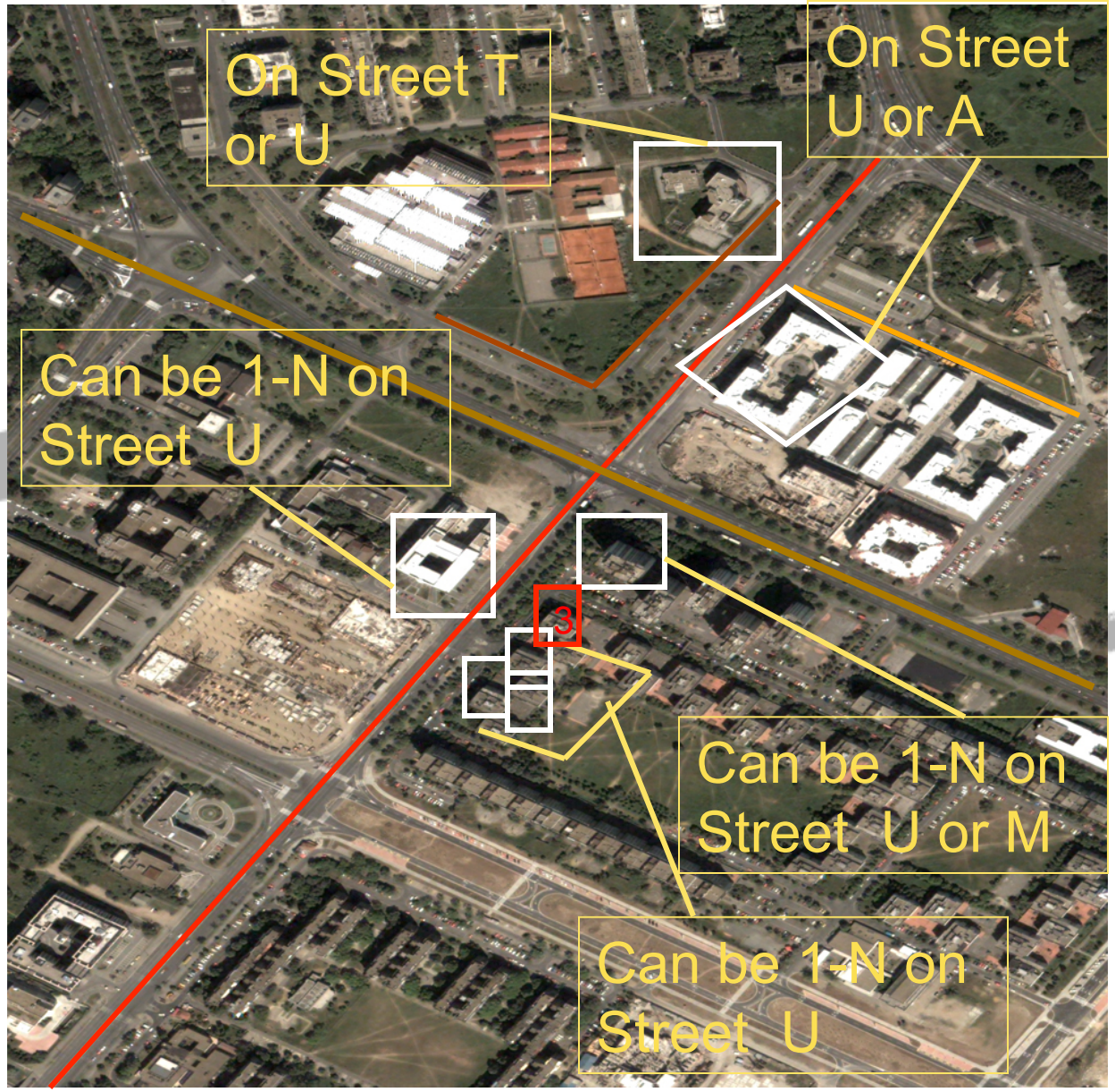


If we know this building must be 3 on street U

Street T
Street U
Street A
Street M

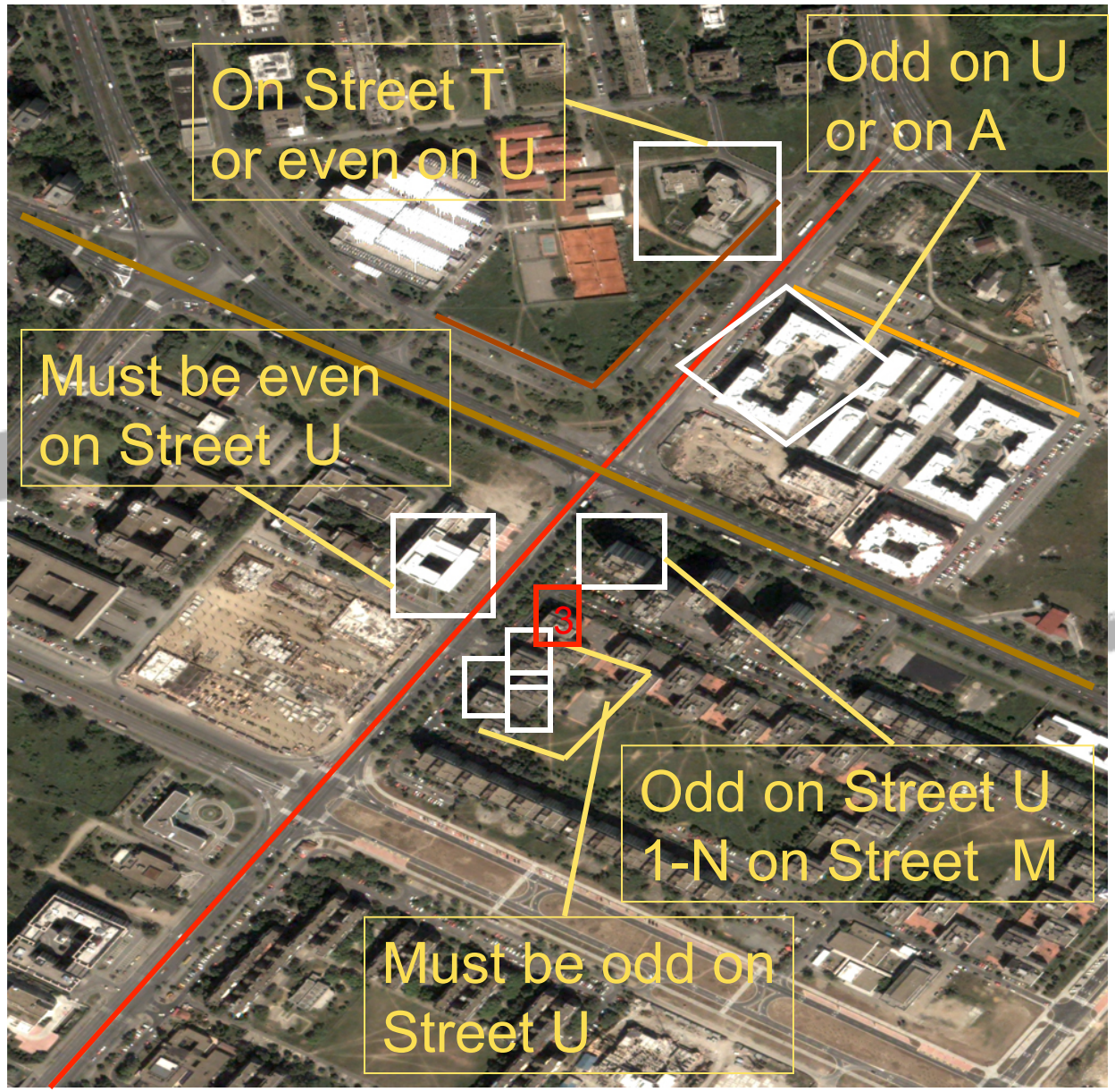
Example

Phone Book:

Nothing on T

1,2,~~3~~,5,7,9 on U

1 on A



Even constraint applied

Street T
Street U
Street A
Street M

Example

Phone Book:

Nothing on T

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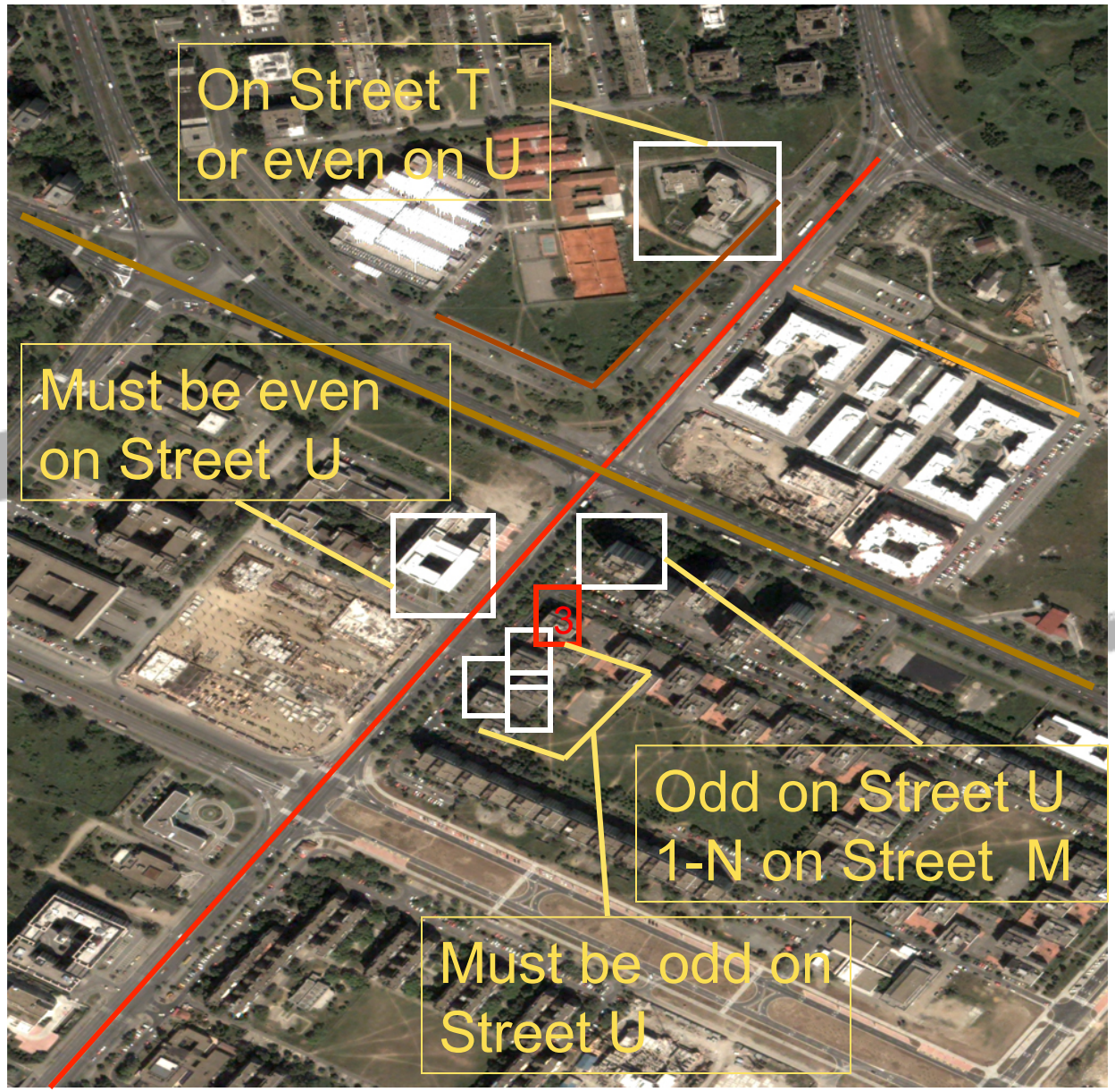
1 on A

Phone book constraint applied

Street T
Street U
Street A
Street M



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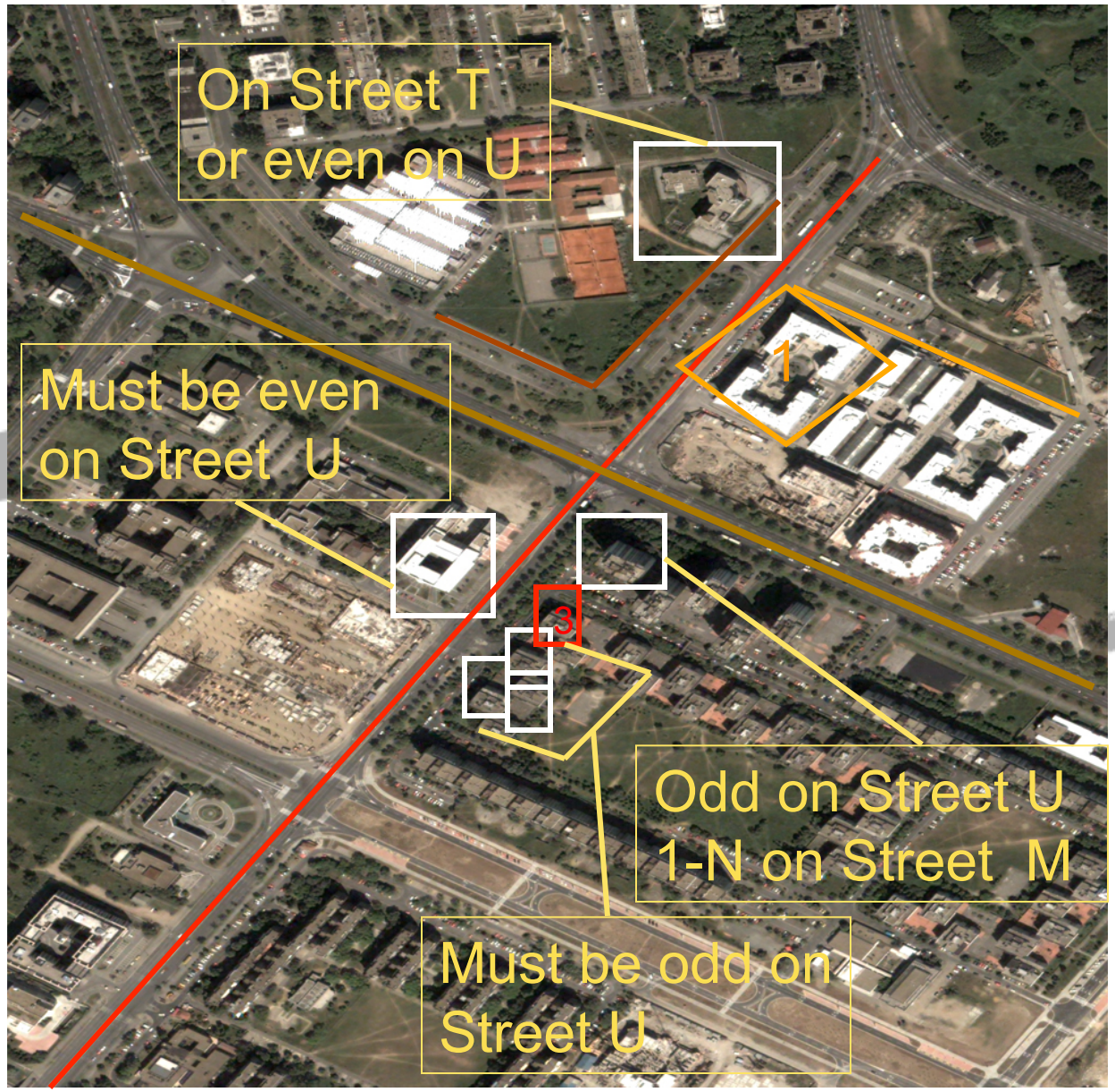

Phone book constraint applied

Street T
Street U
Street A
Street M

Example

Phone Book:

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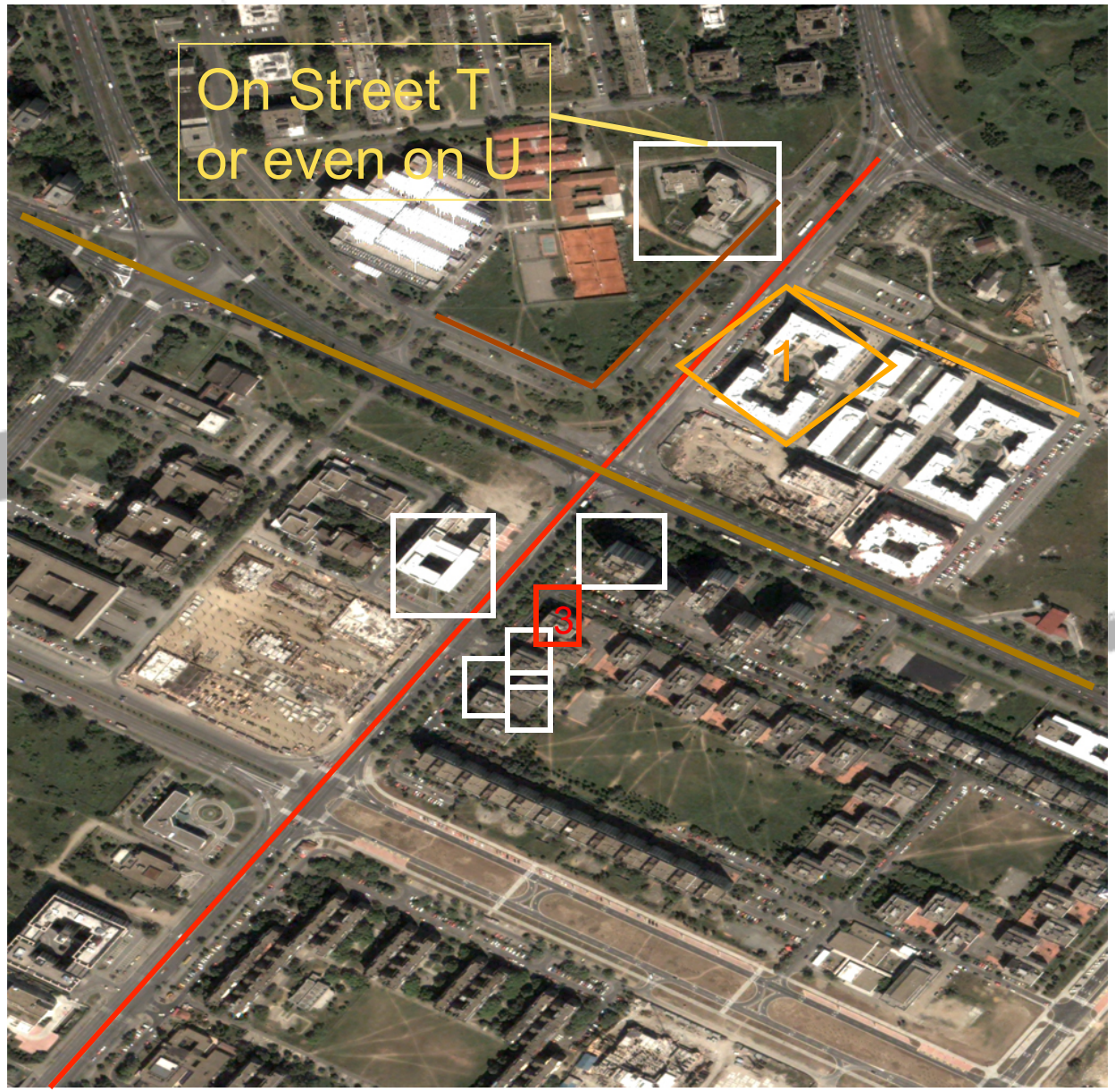


Ordering + Phone book constraint applied

Street T
Street U
Street A
Street M

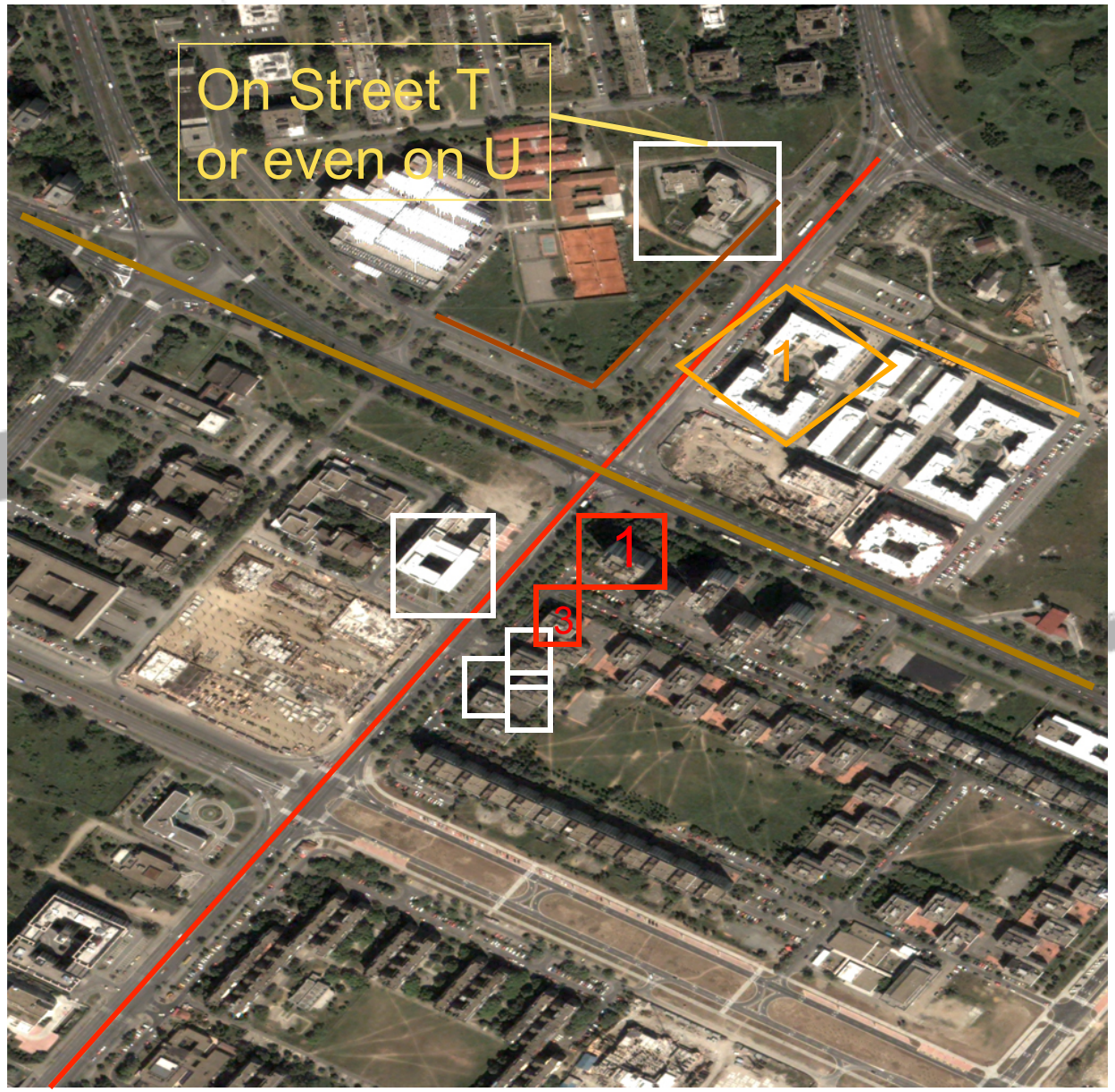
Example

Phone Book:

Nothing on T

~~1~~,2,~~3~~,5,7,9 on U

~~1~~ on A



Ordering + Phone book constraint applied

Street T
Street U
Street A
Street M

Example

Phone Book:

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Ordering + Phone book constraint applied

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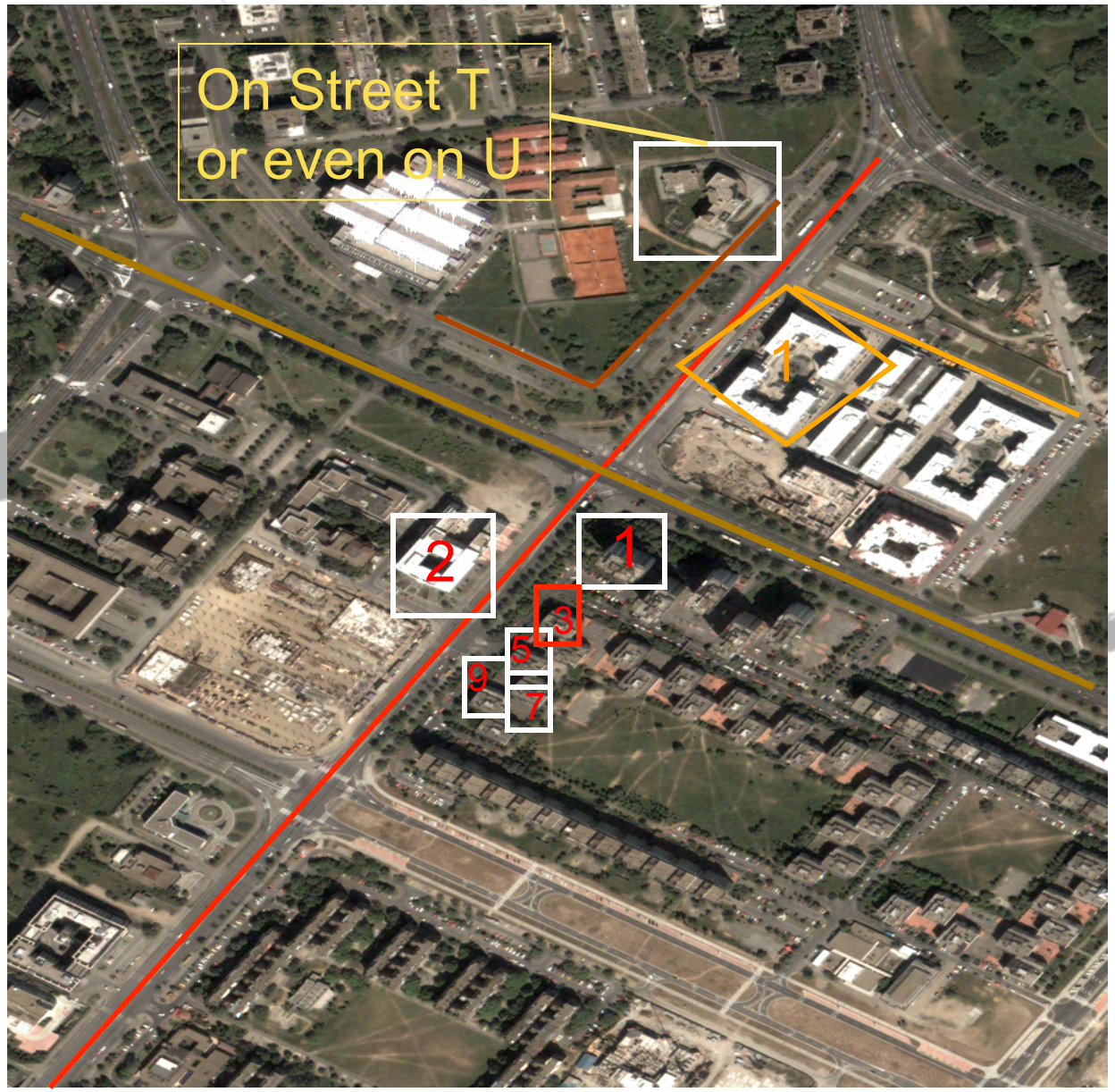

Ordering + Phone book constraint applied

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Ordering + Phone book constraint applied

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Experimental Results

- Two sets of experiments
  - Synthetic
    - Layout of streets and buildings created by us
  - Real-world scenario
    - Using data and layout for a neighborhood in El Segundo CA
- Report Precision and Recall

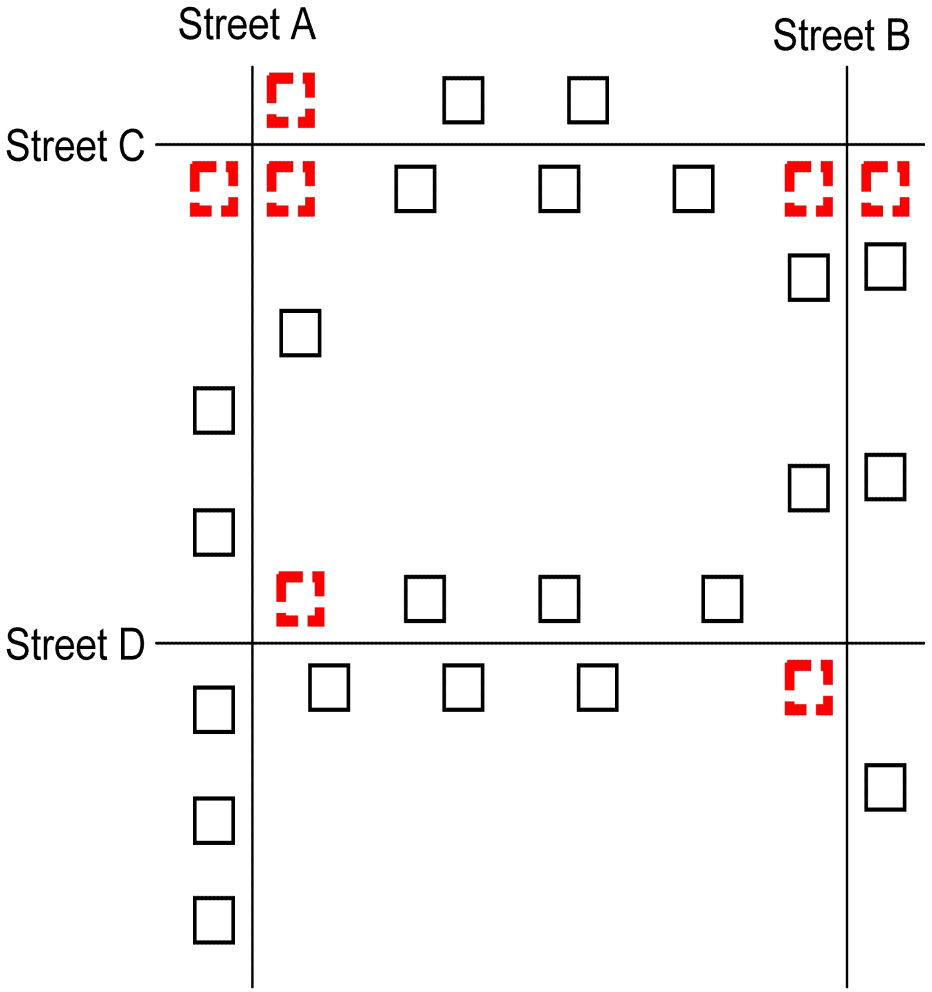
Precision and Recall

$$recall = \frac{correctly\_labeled}{total\_buildings}$$

$$precision = \frac{num\_correct\_assignments}{total\_num\_assignments}$$

- For example
  - Two buildings in an image, two assignments to one building, three to the other, and a correct assignment is made to both
  - recall = 100%, precision = 40%.

Synthetic Experiment



"Phone Book"

Street A = {2,3,4,5,6,7,8,9,11,13}

Street B = {1,2,3,4,5,6,7,8}

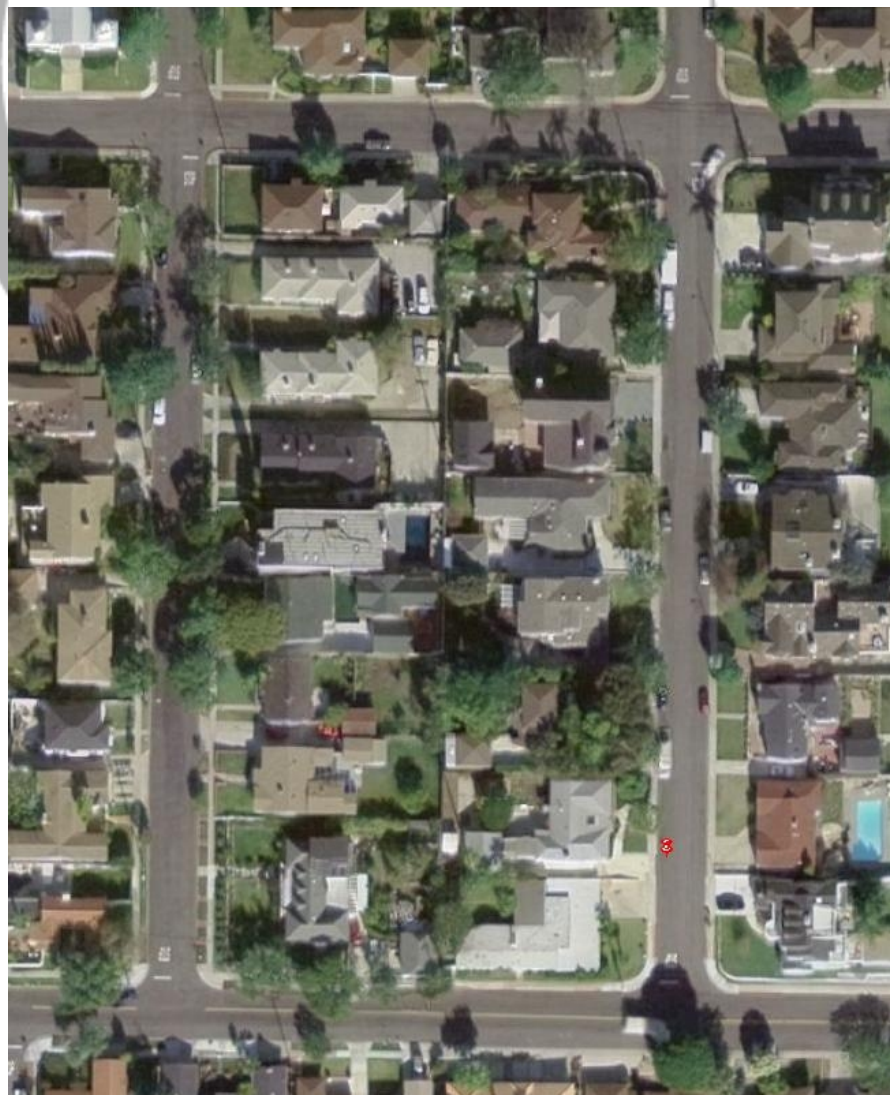
Street C = {1,2,3,4,5}

Street D = {1,2,3,4,5,6}

Synthetic Experiment

Trial Type	Precision	Recall
All information available	100%	100%
All info except even/odd	100%	100%
Missing phone book entries	85.3%	96.6%
Missing entries and no even/ odd	58.6%	96.6%

Real-World Experiment



- El Segundo CA neighborhood
- 34 houses
- 4 cross streets

Real-World Experiment

Source Used	Precision	Recall
Phone book source	54.7%	94.1%
Property tax source	100%	100%

Discussion

- CSP Issues:
  - Only gives a binary decision (yes/no)
- Preferred output
  - Probabilities of assignment
- Probabilistic CSP
  - Assigns probability for a given assignment
- Stochastic CSP
  - Incorporates probabilities and more flexible

Future Work

- Improving accuracy
  - Soft constraints
- Using a probabilistic approach
- Studying scalability
- “Plug-in” capability
  - Plug in region specific information

Thank you!