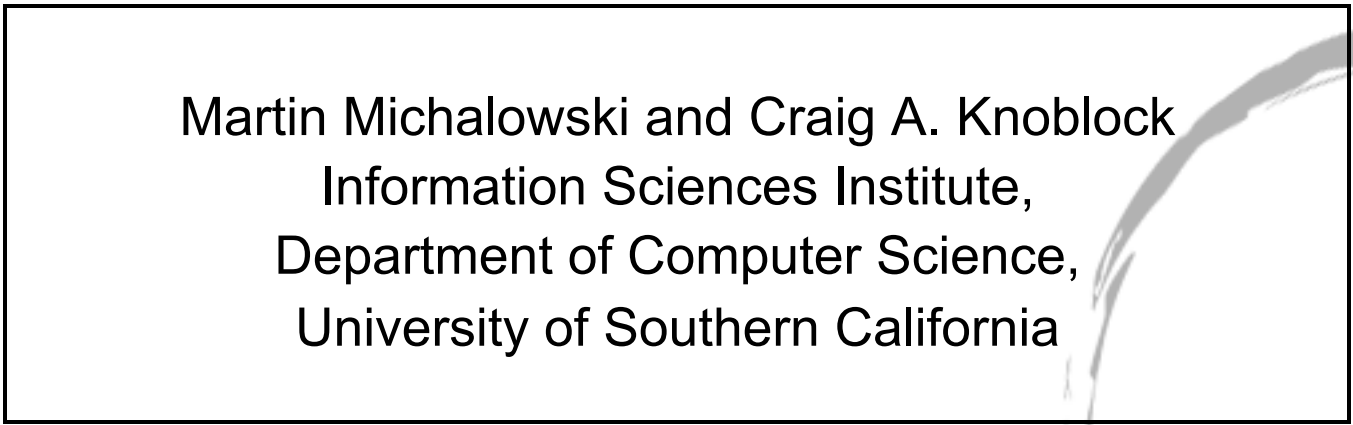
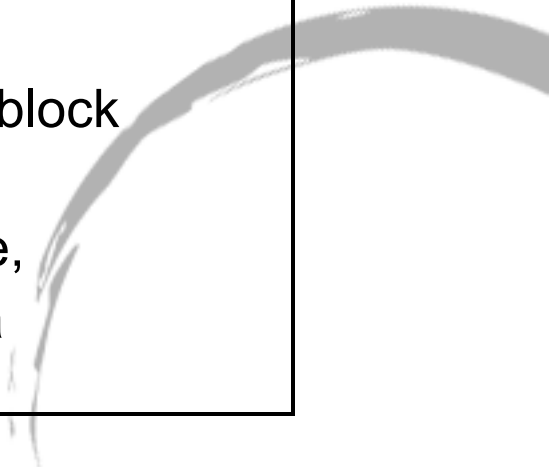




A Constraint Satisfaction Approach to Geospatial Reasoning




Martin Michalowski and Craig A. Knoblock
Information Sciences Institute,
Department of Computer Science,
University of Southern California






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
- 

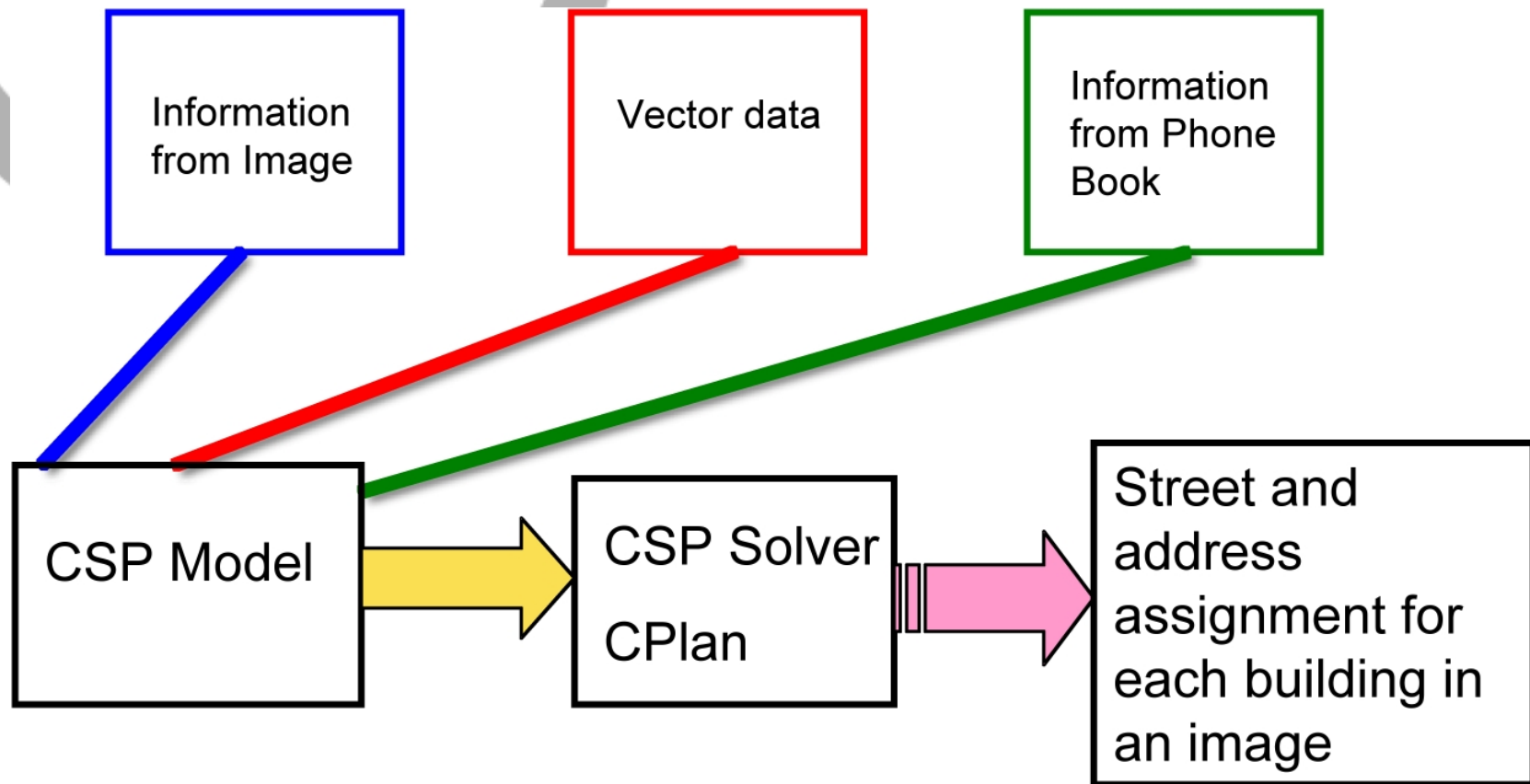
Motivating Example

- 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

The screenshot shows the Telekom Srbija website's telephone directory search page. The header includes the Telekom Srbija logo, a language selector set to 'Serbian', and a search box. The navigation menu contains 'Home', 'Telephone directory', 'Site map', and 'Contact'. The main content area is titled 'Telephone directory' and features two tabs: 'White pages' and 'Yellow pages'. The search form includes a 'Network group' dropdown menu set to 'Beograd - 011', a 'Town' dropdown menu, and several text input fields for 'Phone number', 'Sumame', 'Name', 'Street', and 'Number'. A 'Number of items' dropdown menu is set to '10'. Below the form is an 'Instruction' section and two buttons: 'Search' and 'Reset'. A left sidebar contains a navigation menu with sections for 'About us', 'Services and products', and 'ISDN'.

Telekom Srbija Serbian Search

Home Telephone directory Site map Contact

Telephone directory White pages Yellow pages

Network group: Beograd - 011 Town:

Phone number: Street:

Sumame: Number:

Name: Number of items: 10

Instruction Search Reset

About us

- Introduction
- Organisation of Telekom
- Shareholders
- Telecommunications background

Services and products

- Fixed telephony**
 - Types of equipment
 - Value added services
 - How to become a subscriber
 - HALO payphones and cards
 - Important telephone numbers
 - National area codes
 - International area codes
 - Telephone book
 - Tariff system
- ISDN**
 - ISDN BRI

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)
 - $s_1 \dots s_m = \{\text{streets in image}\}$
 - $\#_1 \dots \#_m = \{\text{set of natural numbers}\}$
 - $e_{ew} = \{N, S\}, e_{ns} = \{W, E\}$
 - $a_{ew} = \{W, E\}, a_{ns} = \{N, S\}$

Constraint Formulation

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

Even or \neg 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

Street A

- BULEVAR AVNOJA

Street M

- BULEVAR MIHAILA
PUPINA



Example

Phone Book:
Nothing on T
1,2,3,5,7,9 on U
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Street T

- TRESNJIN CVET

Street U

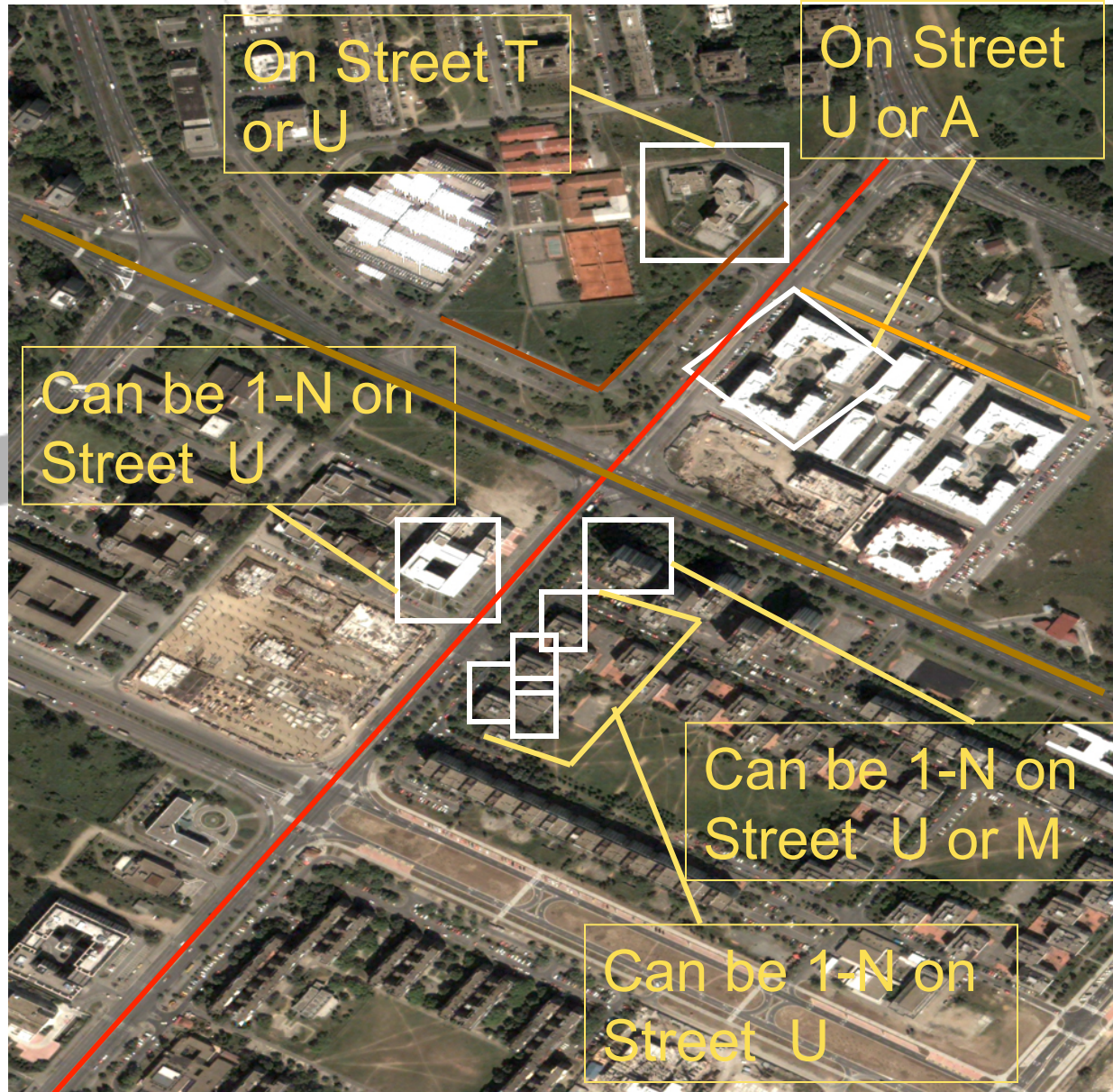
- BULEVAR UMETNOSTI

Street A

- BULEVAR AVNOJA

Street M

- BULEVAR MIHAILA PUPINA

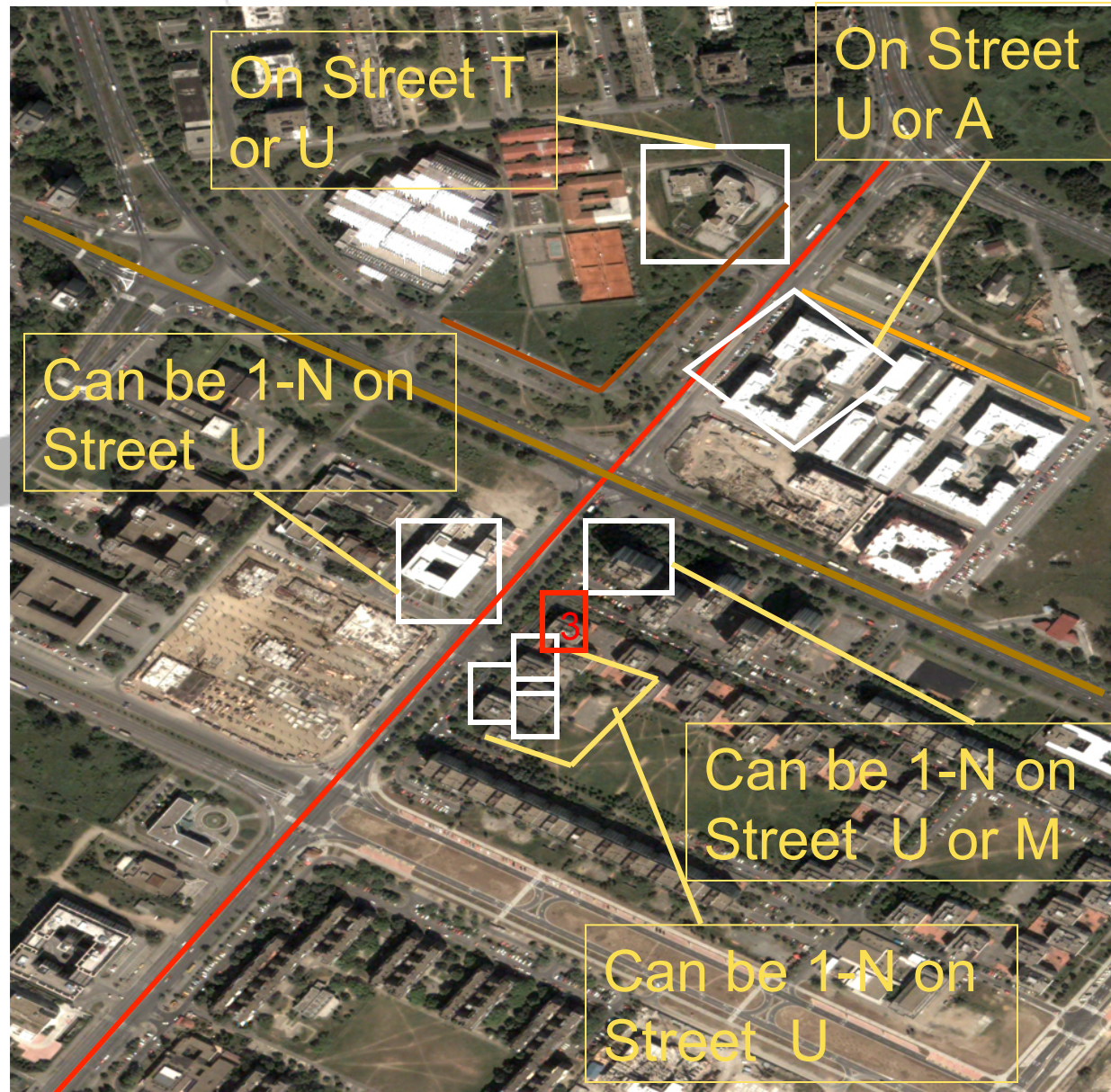


Example

Phone Book:
Nothing on T
1,2,3,5,7,9 on U
1 on A

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

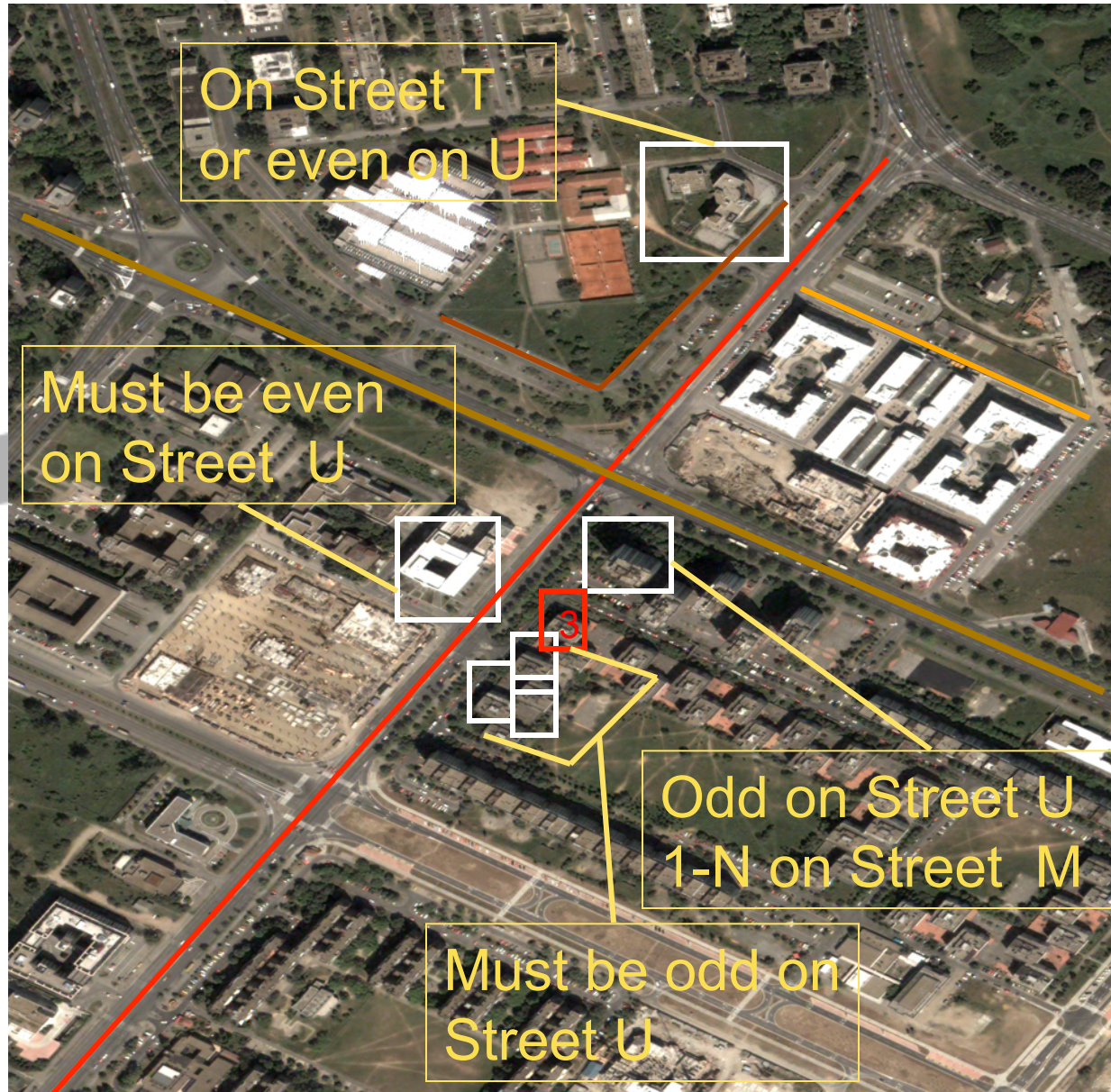


Example

Phone Book:
Nothing on T
1,2,~~3~~,5,7,9 on U
1 on A

Phone book
constraint
applied

Street T
Street U
Street A
Street M

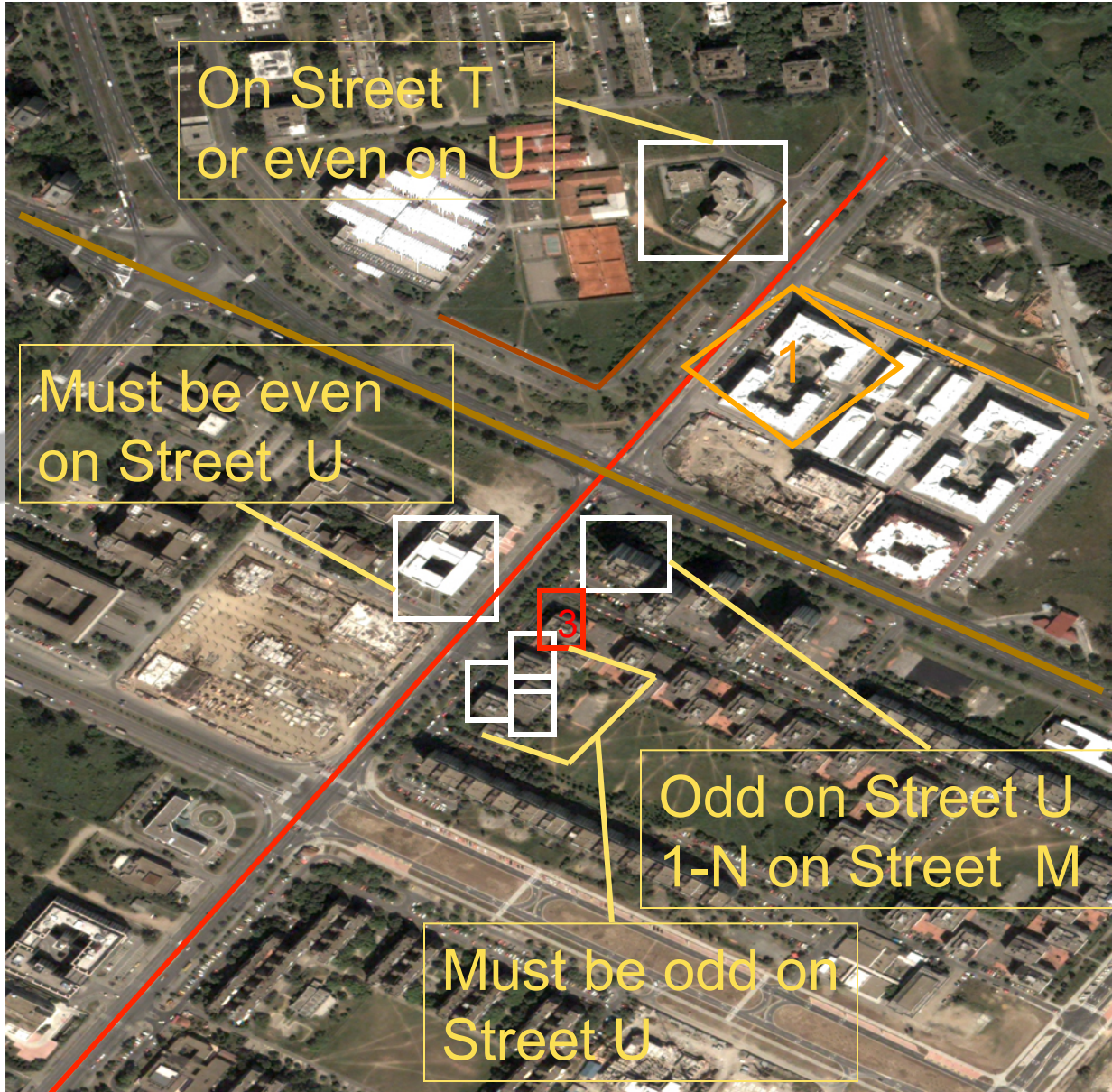


Example

Phone Book:
Nothing on T
1,2,~~3~~,5,7,9 on U
~~1~~ on A

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:
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:
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:
Nothing on T
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Ordering +
Phone book
constraint
applied

Street T
Street U
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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



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

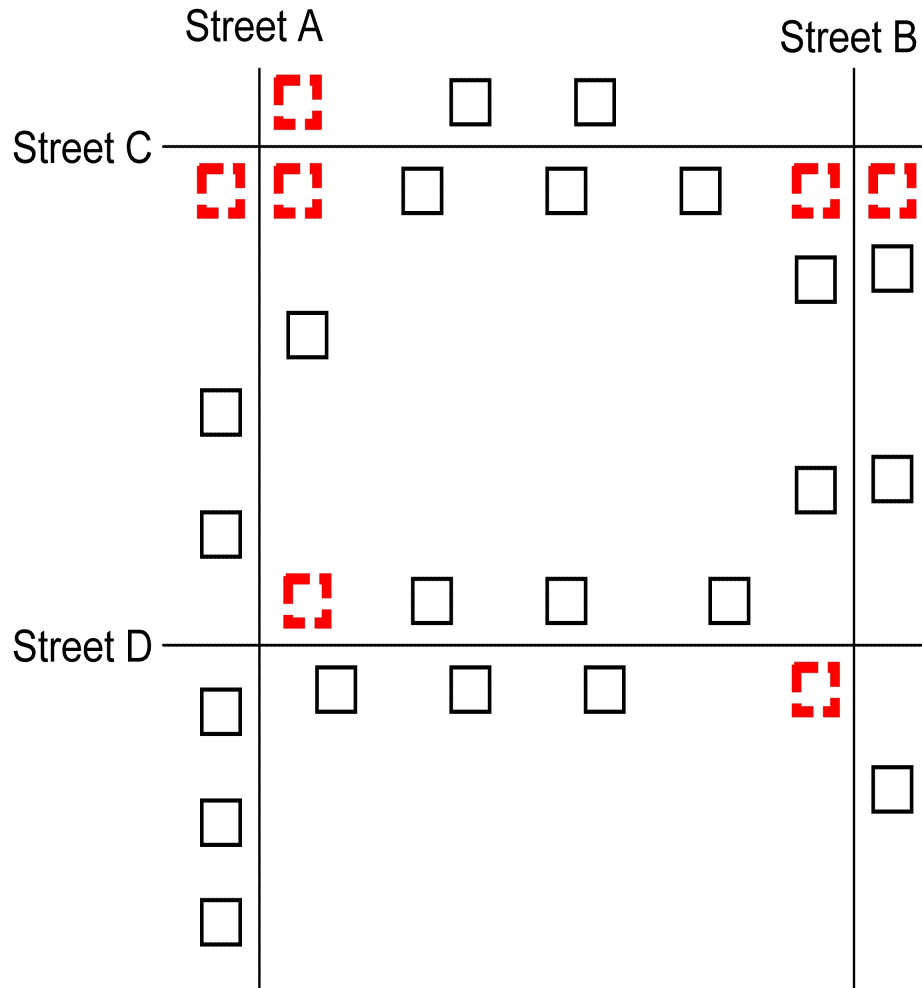
Precision and Recall

$$\textit{recall} = \frac{\textit{correctly_labeled}}{\textit{total_buildings}}$$

$$\textit{precision} = \frac{\textit{num_correct_assignments}}{\textit{total_num_assignments}}$$

- 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!

