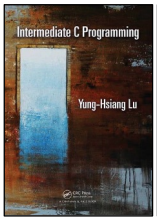
World-Wide Camera Networks

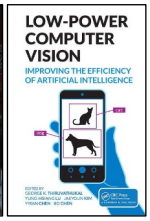
Yung-Hsiang Lu

Professor, Elmore School of Electrical and Computer Engineering, Purdue University
Fellow of the IEEE (2021), Distinguished Visitor of the Computer Society (2023-2025)
Distinguished Scientist and Distinguished Speaker of the ACM (2013)
Director of Purdue John Martinson Engineering Entrepreneurial Center (2020-2022)

Low-Power Computer Vision: Improve the Efficiency of Artificial Intelligence (ISBN 9780367744700)
Intermediate C Programming (ISBN 9781498711630)

PURDUE UNIVERSITY





Let's have a discussion.

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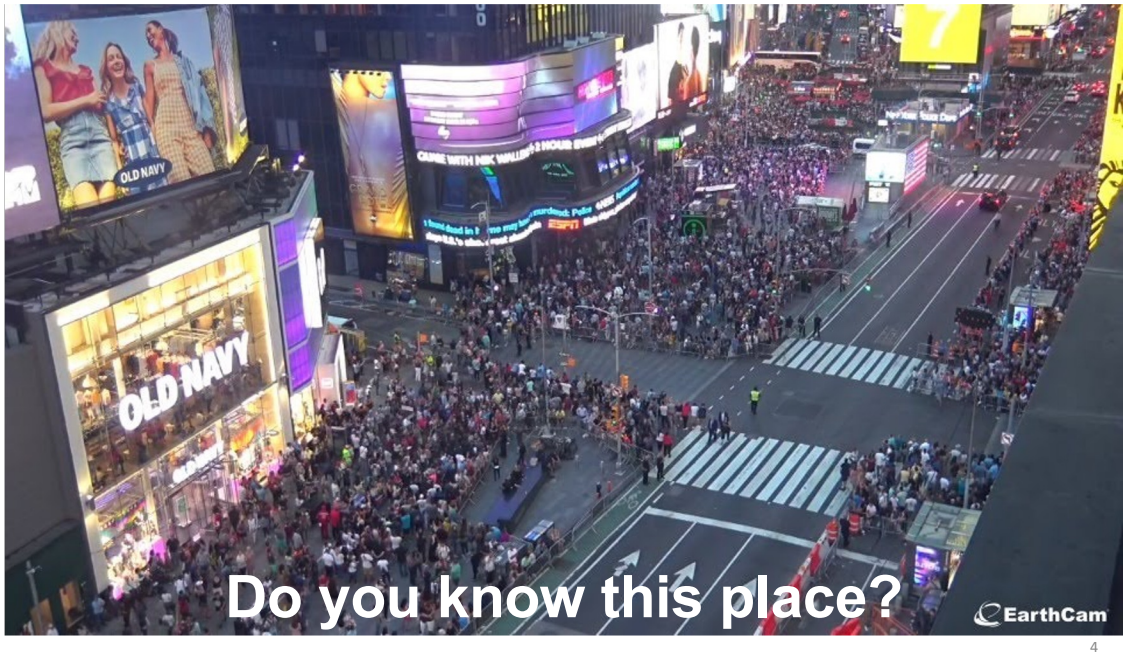
Outlines

- Observing Human Mobility Internationally During COVID-19
- Discovery of Network Cameras
- Resource Management for Analyzing Video Streams from Network Cameras
- Lessons learned (research vs. commercialization)

3



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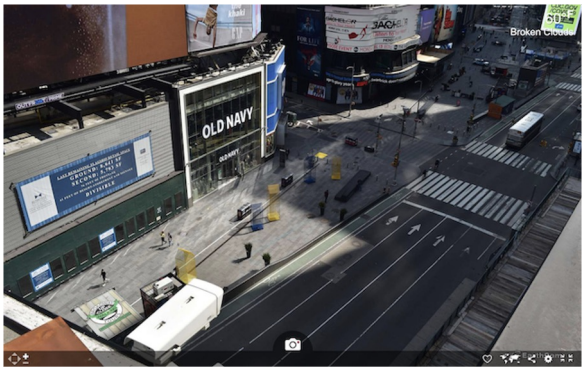
Courtesy of EarthCam


HE TEMPLE BAR
APPY ST PATRICKS DAY
THE TEMPLE B

6

2019

2020/04



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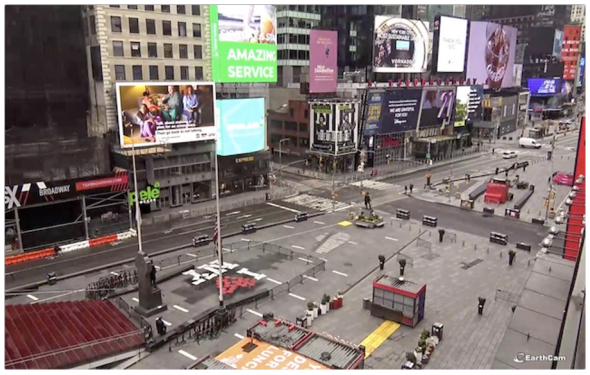
2019

2020/04



8

2019 **2020/04**

Thank You

- Utility
- Network
- Public Safety
- First Responders
- Childcare
- Energy
- …
- many more

Observing Human Mobility Internationally During COVID-19

Shane Allcroft, **Mohammed Metwaly**, **Zachery Berg**, **Isha Ghodgaonkar**, **Fischer Bordwell**, **XinXin Zhao**, **Xinglei Liu**, **and Jiahao Xu**, Purdue University

Subhankar Chakraborty, Indian Institute of Technology Madras

Vishnu Banna, **Akhil Chinnakotla**, **Abhinav Goel**, **Caleb Tung**, **Gore Kao**, **and Wei Zakharov**, Purdue University

David A. Shoham, East Tennessee State University

George K. Thiruvathukal, Loyola University Chicago

Yung-Hsiang Lu, Purdue University

IEEE Computer March 2023

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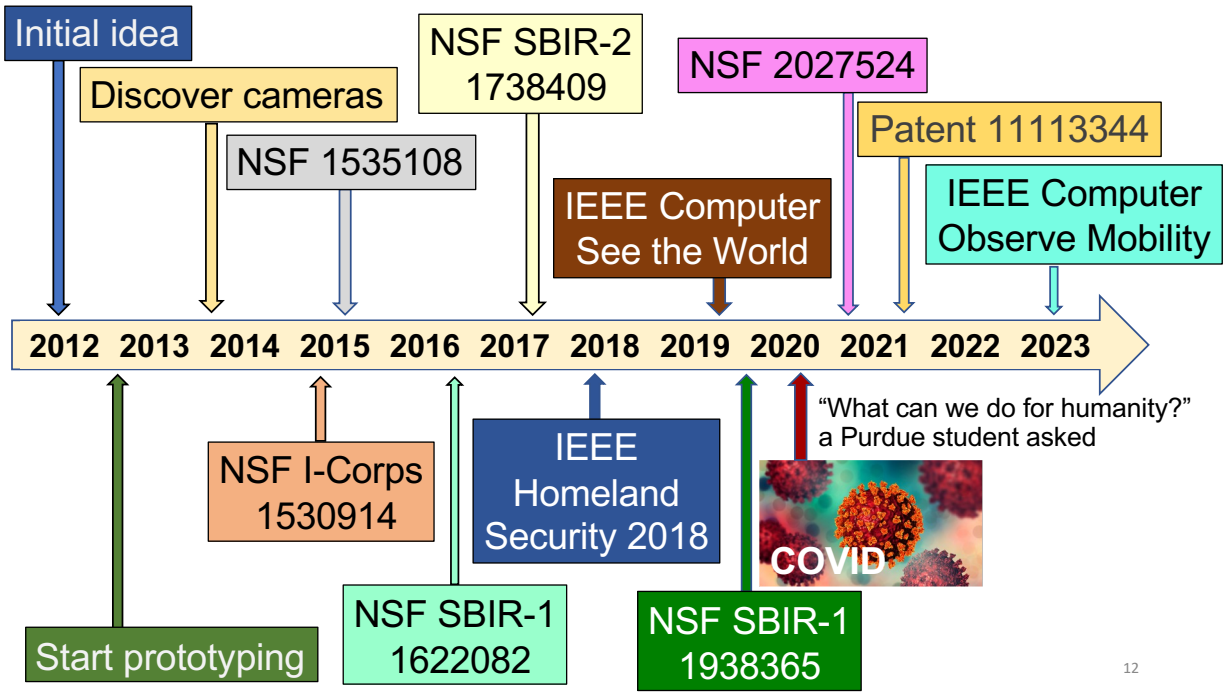

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PURDUE UNIVERSITY GIVE TO

PROTECT PURDUE PLEDGE ESSENTIAL GUIDANCE SUMMARY REPORT LATEST UPDATES

Protect Purdue > Latest Updates > **March 10th COVID-19 Update from President Daniels and Provost Akridge**

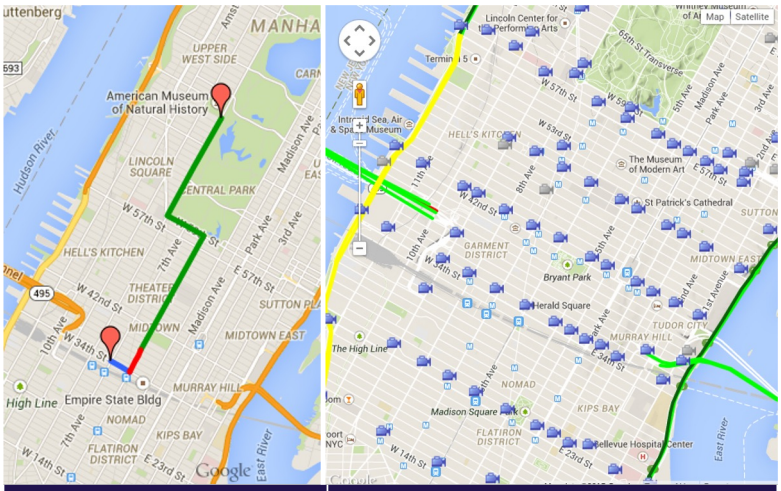
MARCH 10TH COVID-19 UPDATE FROM PRESIDENT DANIELS AND PROVOST AKRIDGE

MARCH 10, 2020

All faculty and staff should move their courses to online or alternative delivery before March 23 and should be prepared to continue as long as in-person instruction seems inadvisable [13]

2012: “Can we see the world at home?”

2014 Thanksgiving Parade in NYC



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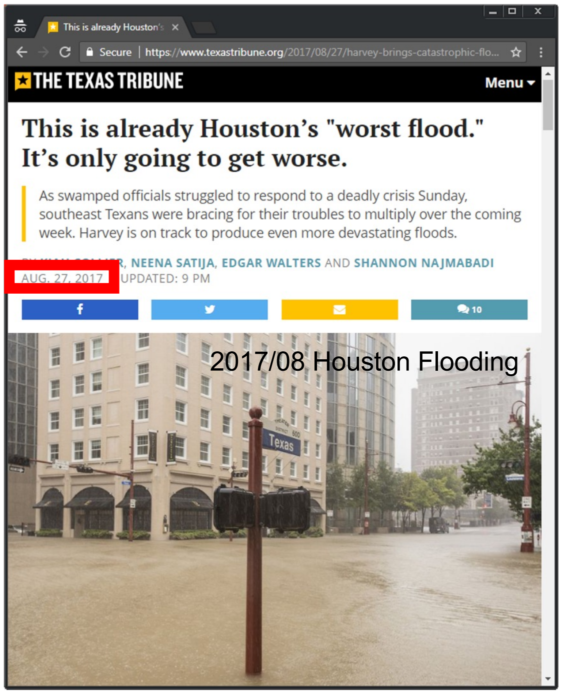
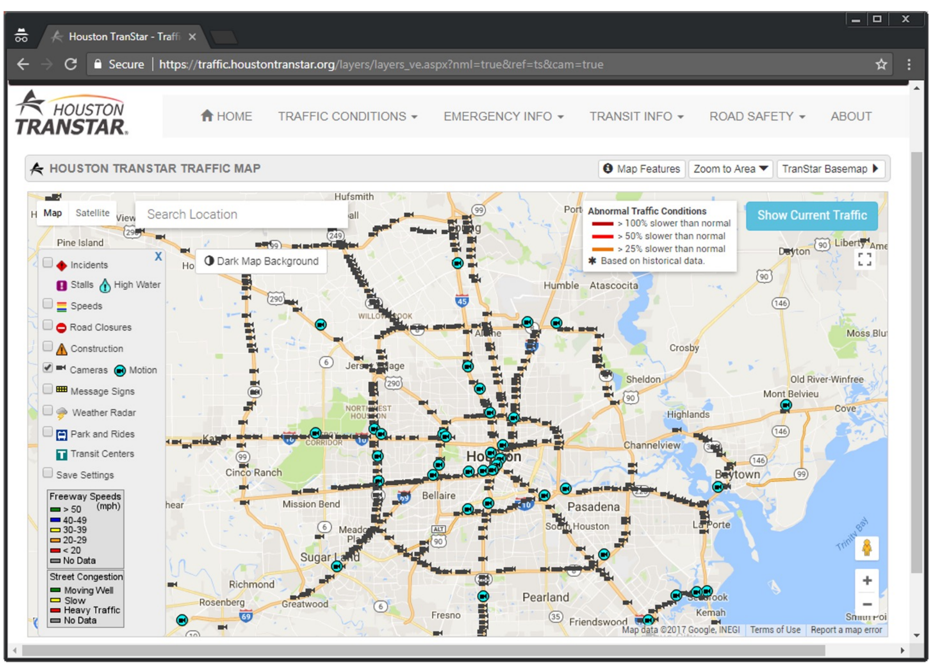
16


This is already Houston's
https://www.texastribune.org/2017/08/27/harvey-brings-catastrophic-flo...
THE TEXAS TRIBUNE
Menu
This is already Houston's "worst flood." It's only going to get worse.
As swamped officials struggled to respond to a deadly crisis Sunday, southeast Texans were bracing for their troubles to multiply over the coming week. Harvey is on track to produce even more devastating floods.
NEENA SATIJA, EDGAR WALTERS AND SHANNON NAJMABADI
AUG. 27, 2017
UPDATED: 9 PM
2017/08 Houston Flooding
Texas

17


Houston TranStar - Traffi
https://traffic.houstontranstar.org/layers/layers_ve.aspx?nml=true&ref=ts&cam=true
HOUSTON TRANSTAR
HOME
TRAFFIC CONDITIONS
EMERGENCY INFO
TRANSIT INFO
ROAD SAFETY
ABOUT
HOUSTON TRANSTAR TRAFFIC MAP
Map Features
Zoom to Area
TranStar Basemap
Map
Satellite
Search Location
Dark Map Background
Abnormal Traffic Conditions
> 100% slower than normal
> 50% slower than normal
> 25% slower than normal
Based on historical data.
Show Current Traffic
Incidents
Stalls
High Water
Speeds
Road Closures
Construction
Cameras
Motion
Message Signs
Weather Radar
Park and Rides
Transit Centers
Save Settings
Freeway Speeds (mph)
> 50
40-49
30-39
20-29
< 20
No Data
Street Congestion
Moving Well
Slow
Heavy Traffic
No Data
Houston
Pasadena
Baytown
Pearland
Sugar Land
Map data ©2017 Google, INEGI
Terms of Use
Report a map error

18


I-69 Eastex @ Hopper
08/27/2017 09:10:19 1222
Copyright ©2017 Houston TranStar
I-69 Eastex @ Tidwell
08/27/2017 09:10:02 1217
Copyright ©2017 Houston TranStar
I-610 E Loop @ Market Street
08/28/2017 09:20:50 651
Copyright ©2017 Houston TranStar
I-69 Eastex @ Parker
08/28/2017 09:24:12 1219
Copyright ©2017 Houston TranStar

19


I-69 Eastex @ Parker
08/28/2017 09:24:12 1219
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20


I-69 Eastex @ Parker
HOUSTON TRANSTAR
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I-69 Eastex @ Parker
HOUSTON TRANSTAR
08/28/2017 09:24:12
1219
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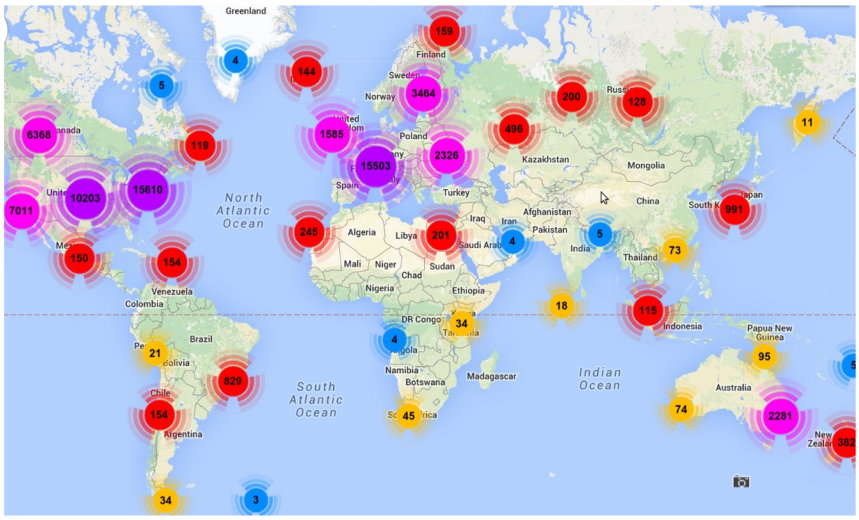
We discovered more than 120,000 cameras now, analyze 5 seconds/camera ⇒ 7 days (no sleep)



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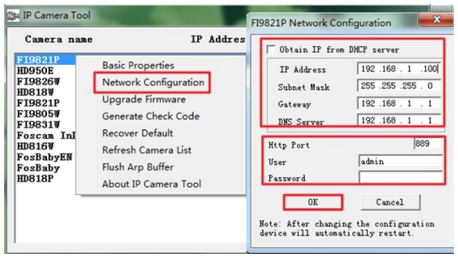
How to Discover and Use the Data?

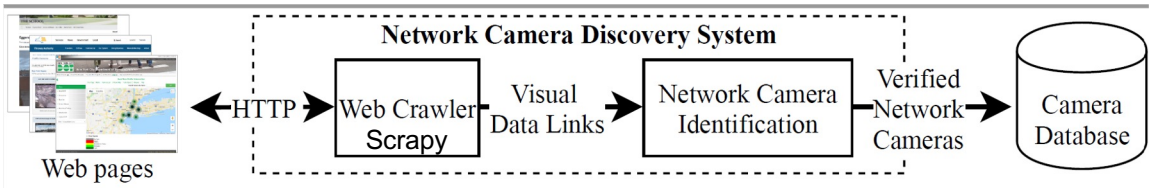
- "Automated Discovery of Network Cameras in Heterogeneous Web Pages ", ACM Transactions on Internet Technology, Vol. 22, Issue 1. February 2022
- "Observing Human Mobility Internationally During COVID-19", Computer 2023
- "Adaptive Resource Management for Analyzing Video Streams from Globally Distributed Network Cameras", IEEE Transactions on Cloud Computing, Vol. 9, Issue 1, January 2021.

Discover Network Cameras

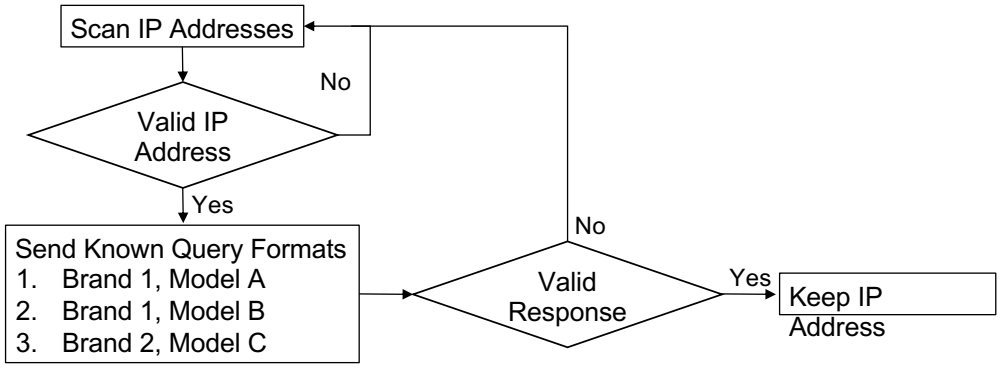
Network cameras: cameras connected to the Internet providing (near) real-time data.

1. Cameras with individual IP addresses
2. Multiple cameras on websites





Cameras with Individual IP Addresses



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IP Address Ranges of Universities

URL	IP Address
www.purdue.edu	128.210.7.200
www.stanford.edu	146.75.30.133
www.mit.edu	23.79.197.77
www.berkeley.edu	141.193.213.21

- Informed Purdue Network Security Office before the scan
- Problems:
  - Slow (one minute per camera), Low success rate (< 0.1%)
  - Discover only several known brands
  - Miss many cameras that do not have individual IP addresses
  - Cannot find cameras' locations easily
  - Appear security attacks (denial of service, vulnerability exploration)

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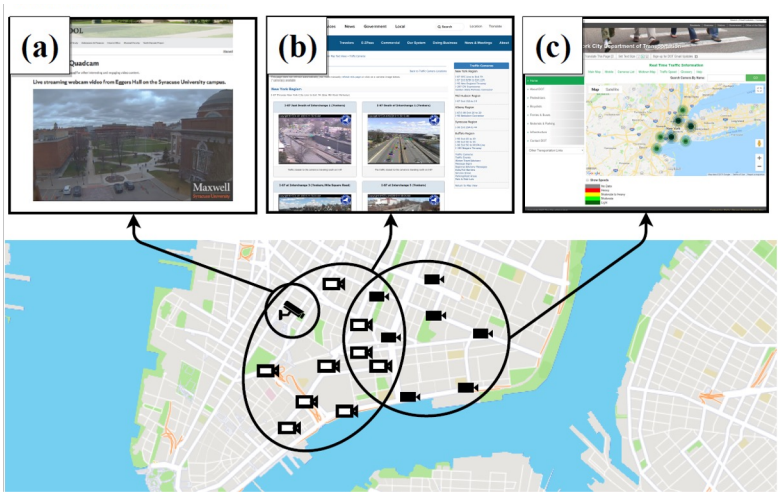
Cameras on websites (three organizations)



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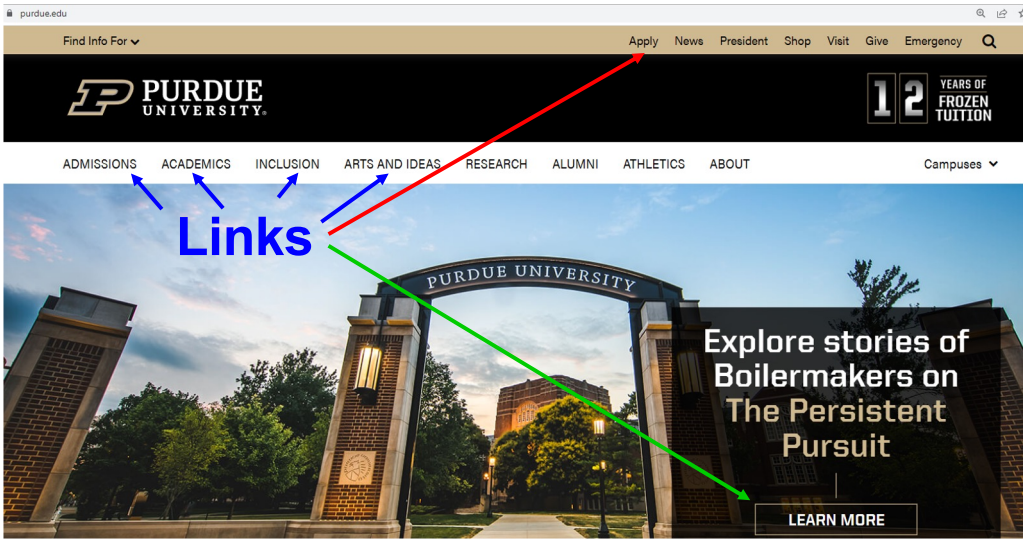
How do web crawlers work?



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Engineering Webcams

PURDUE UNIVERSITY

The Engineering Computer Network maintains webcams in several buildings. They d
construction projects and provide a glimpse into Purdue for those far away.

Click on a photo to view a slide show from the past day, month, year or all images.

Bowen Labs Cam 1

Last updated April 15, 2023 10:40 am

Bowen Labs Cam 2

Last updated April 15, 2023 10:40 am

Bowen Labs Cam 3

Last updated April 15, 2023 10:40 am

Bowen Labs Cam 4

Last updated April 15, 2023 10:40 am

Purdue Memorial Union South Terraces

from roof of Rawls

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University of Illinois Alma Cam

32

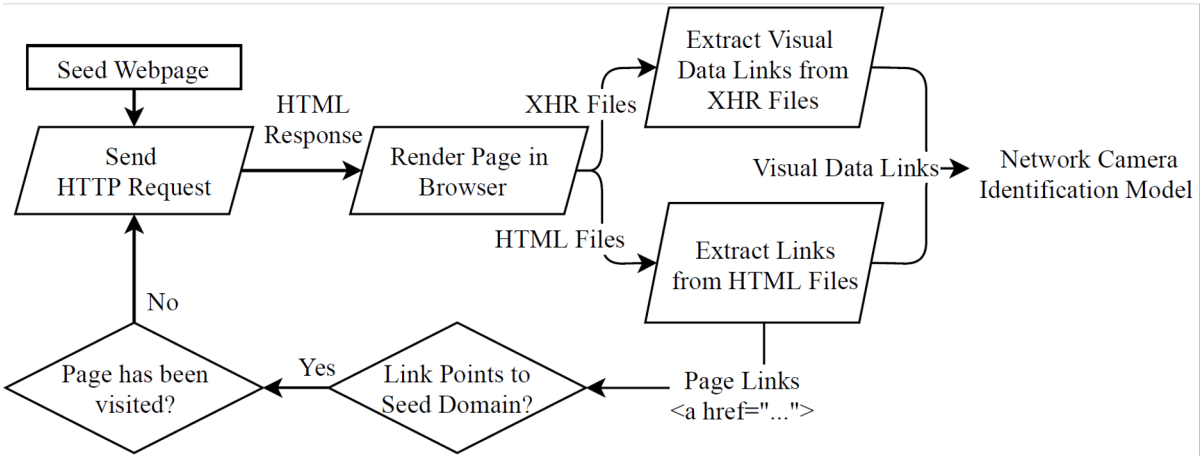
University of Iowa Pentacrest Webcam

33

Tokyo Shinjuku

Japan Intersection

Discover cameras on websites



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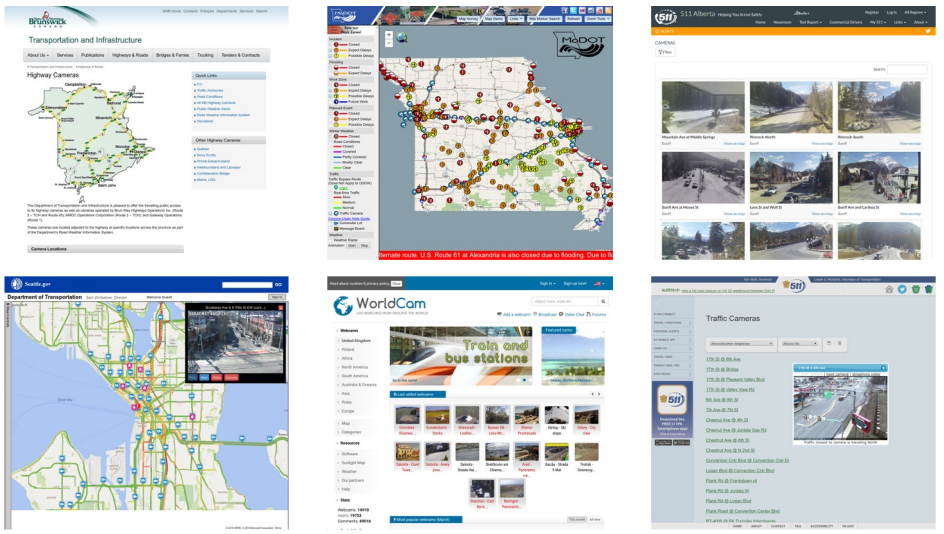
Challenge 1: different HTML structures



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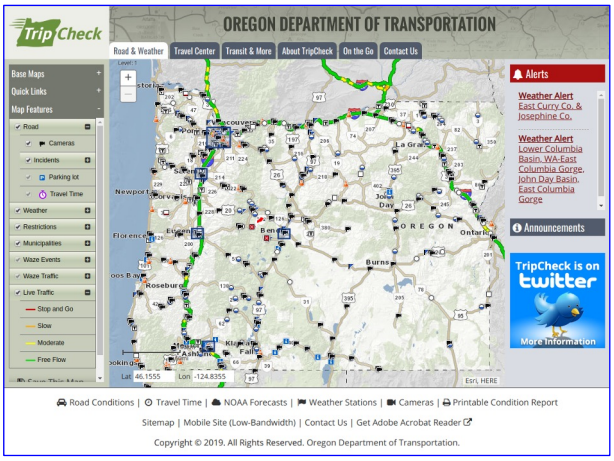
Challenge 2: Javascript



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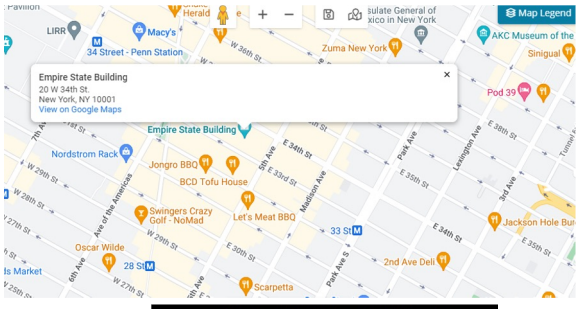
Challenge 3: Locations

From Data Sources



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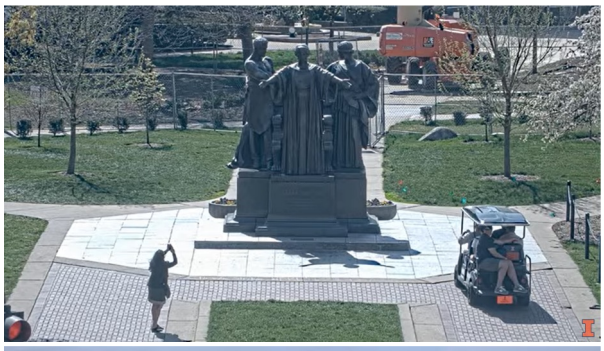


Match weather reports

Hourly Weather - Urbana, IL
As of 10:22 am CDT

There is a possible risk of severe weather today.

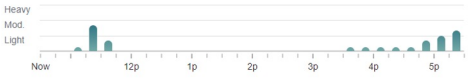
Saturday, April 15

10:15 am	74°	Sunny	0%	SSW 15 mph
10:30 am	75°	Sunny	0%	SSW 15 mph
10:45 am	76°	Sunny	0%	SSW 15 mph

Hourly Weather - Iowa City, IA
As of 10:25 am CDT

There is a marginal risk of severe weather today.

Thunderstorms possible after 11 am.



Saturday, April 15

10:30 am	63°	Sunny	7%	SSW 18 mph
10:45 am	64°	Sunny	11%	SSW 19 mph

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Match Google Street

Network Camera

Google Street

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Detect Static Visual Data

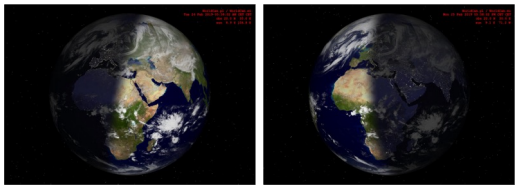
Detect and exclude static visual data (icons and recorded videos)

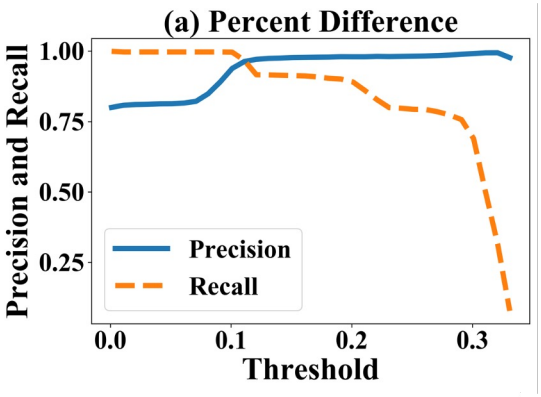
Icons:

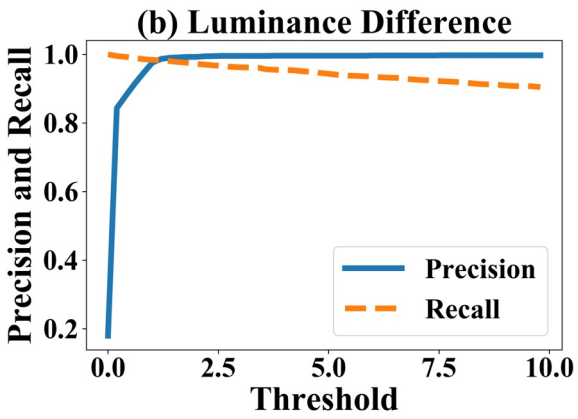
Good Result:

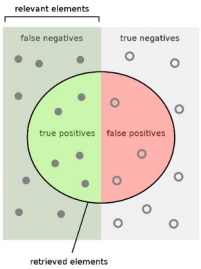
Solution: detect time-changing visual data

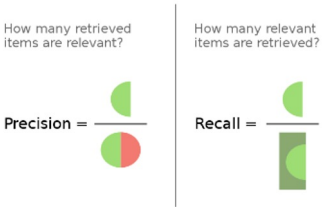
False Positive:











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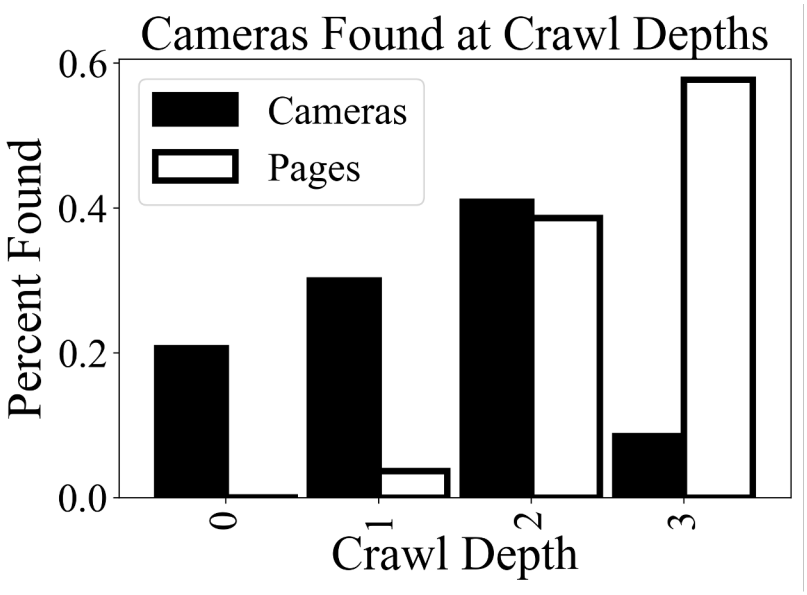

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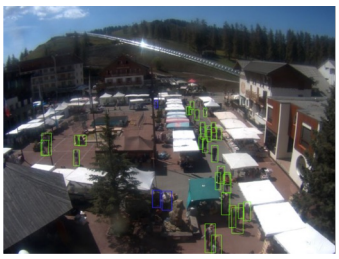
Count People during COVID



2020/08/11 France

2020/12/29 Kerns

2020/05/15 Zatec

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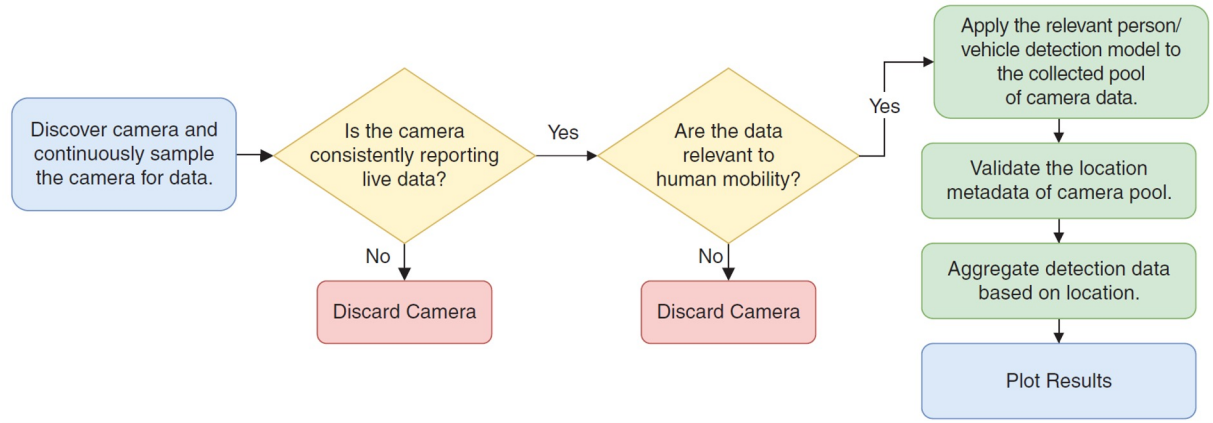
Discover camera and continuously sample the camera for data.
Is the camera consistently reporting live data?
Yes
No
Discard Camera
Are the data relevant to human mobility?
Yes
No
Discard Camera
Apply the relevant person/ vehicle detection model to the collected pool of camera data.
Validate the location metadata of camera pool.
Aggregate detection data based on location.
Plot Results

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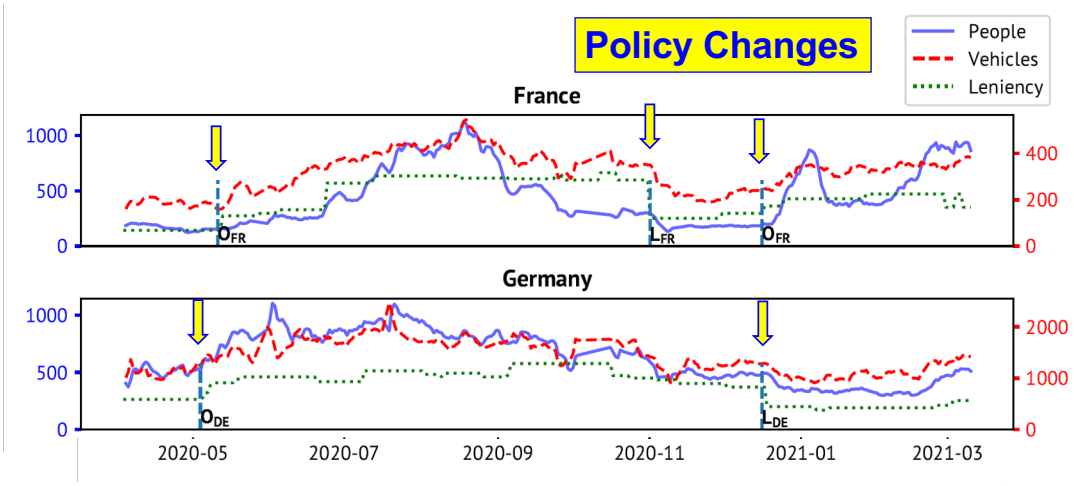
Policy Changes
People
Vehicles
Leniency
France
1000
500
0
400
200
0
O_{FR}
L_{FR}
O_{FR}
Germany
1000
500
0
2000
1000
0
O_{DE}
L_{DE}
2020-05
2020-07
2020-09
2020-11
2021-01
2021-03

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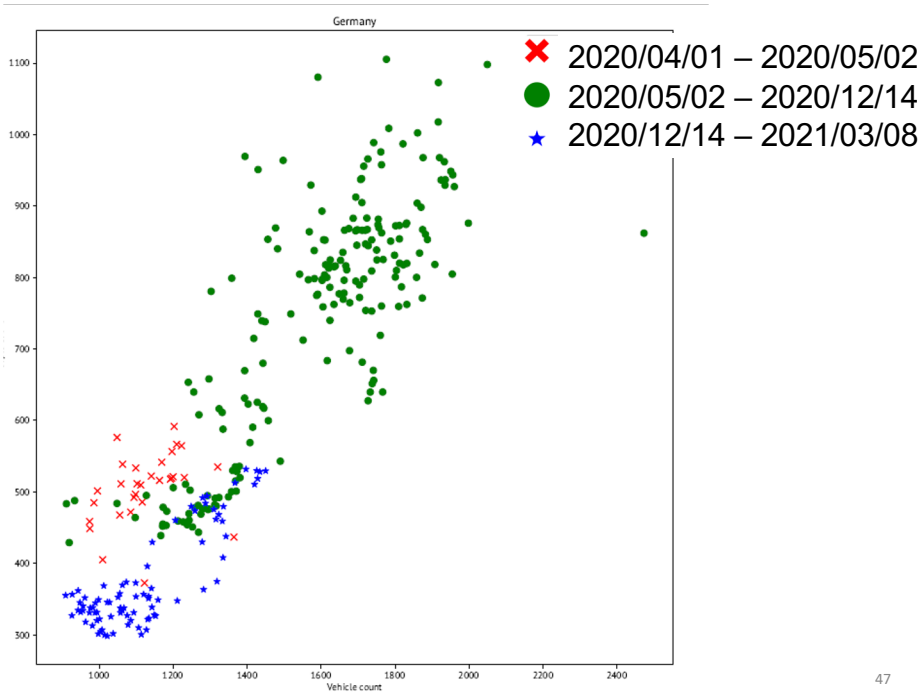

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Limitations of this study

- No historical data for seasonal adjustments
- Only outdoor data, only public locations
- Due to the volume of data, low sampling rates
- Cannot detect face masks (too few pixels for faces)
- Cameras may be disconnected by owners

- Privacy Policy: This project is approved by Purdue's Institutional Review Board (IRB). The project counts numbers of people and vehicles. The project does not recognize faces or license plates.

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Questions and Discussion

Analyze Global Real-Time Video Streams

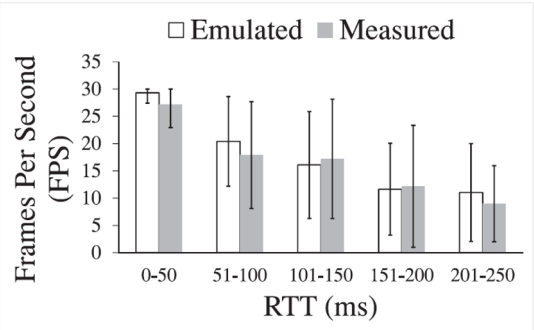
- The cameras are globally distributed.
- Moving data across long distances increases latency and reduces frame rates.
- Cloud instances have different costs at different locations

Instance	Virginia, Oregon	Frankfurt	Singapore	Tokyo
m3.medium	0.067	0.079	0.098	0.096
m3.large	0.133	0.158	0.196	0.193
m3.xlarge	0.266	0.316	0.392	0.385
m3.2xlarge	0.532	0.632	0.784	0.770

Amazon EC2 m3 instance cost per hour

Research Questions

- Where should the data be analyzed?
- Which cloud instances should be used?
- How many should be allocated?



Round-Trip Time (RTT) and Frame Rates for MJPEG

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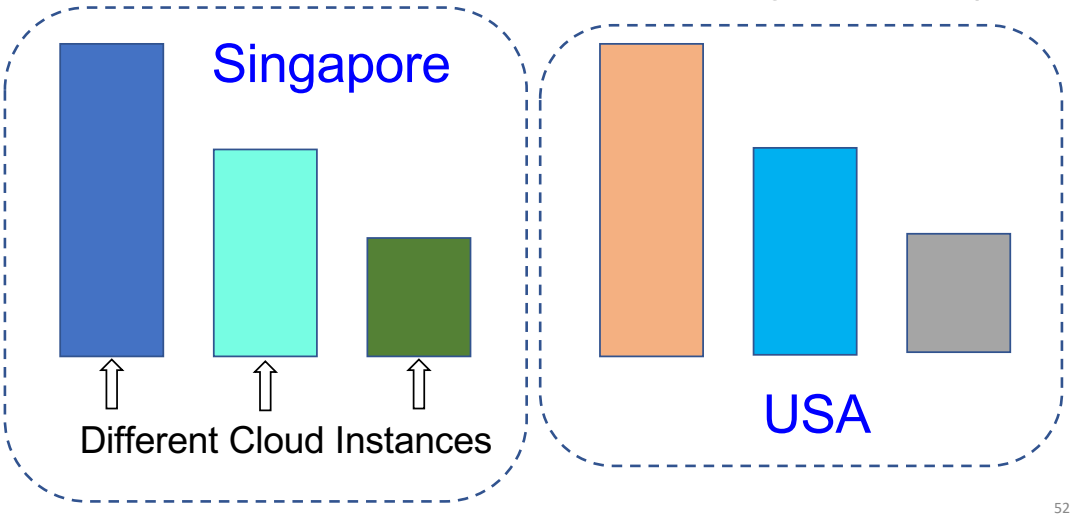
Problem Formulation (Multiple-size bin packing problem)



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Commercialization?

- We created “interesting” technology (papers + patents)
- We could see many places in the world instantaneously.
- We have methods to analyze the data efficiently.
- What is the product? Who are the customers?
- Three people in this research team joined NSF I-Corps for “customer discovery”

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Business Model Canvas				
Key Partners	**Key Activities**	**Value Proposition**	**Customer Relationships**	**Customer Segments**
	Key Resources		**Channels**	
Cost Structure		**Revenue Streams**		

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Research vs. Commercialization

- Publishing papers different from developing products
- Creating profitable products require long-term planning
- University structures create predictable disruptions:
  - Semester breaks
  - Existing students graduate, new students join
  - “Build from scratch” common; “Build upon existing” rare
  - Documentation and transition not emphasized
  - Low correlations between grades and research abilities

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Summary

- Network cameras provide (near) real-time visual data
- Discovering network cameras has to handle heterogeneity
- Analyzing the data efficiently needs to consider locations of computation
- Research different from commercialization
- Please share your comments, questions, and suggestions to yunglu@purdue.edu.
- Thank you.

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Representative Publications

- “Observing Human Mobility Internationally During COVID-19”, Computer 2023, Volume: 56, Issue: 3, pages 59-69, DOI: https://doi.org/10.1109/MC.2022.3175751
- “Automated Discovery of Network Cameras in Heterogeneous Web Pages “, ACM Transactions on Internet Technology, Vol. 22, Issue 1. February 2022, DOI: https://doi.org/10.1145/3450629
- “See the World through Network Cameras”, IEEE Computer pages 30-40, Vol. 52, Issue 10, October 2019. DOI: https://doi.org/10.1109/MC.2019.2906841
- “Adaptive Resource Management for Analyzing Video Streams from Globally Distributed Network Cameras”, IEEE Transactions on Cloud Computing, Vol. 9, Issue 1, January 2021. Pages: 40-53. DOI: https://doi.org/10.1109/TCC.2018.2836907
- “Cloud Resource Management for Analyzing Big Real-Time Visual Data from Network Cameras”, IEEE Transactions on Cloud Computing, Pages 935-948, Vol. 7, Issue 4, October-December 2019. DOI: https://doi.org/10.1109/TCC.2017.2720665
- “Large-Scale Object Detection of Images from Network Cameras in Variable Ambient Lighting Conditions”, IEEE International Conference on Multimedia Information Processing and Retrieval 2019. DOI: https://doi.org/10.1109/MIPR.2019.00080

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- “Cross-referencing social media and public surveillance camera data for disaster response”, IEEE Symposium on Technologies for Homeland Security 2018. DOI: https://doi.org/10.1109/THS.2018.8574200
- “Location Based Cloud Resource Management for Analyzing Real-Time Video from Globally Distributed Network Cameras”, IEEE International Conference on Cloud Computing Technology and Science (CloudCom) 2016. Pages: 176-183. DOI: https://doi.org/10.1109/CloudCom.2016.0040
- “Improve Safety using Public Network Cameras, IEEE Symposium on Technologies for Homeland Security 2016. DOI: https://doi.org/10.1109/THS.2016.7568911
- “Large-scale Image Processing using Amazon EC2 Spot Instances”, IS&T International Symposium on Electronic Imaging in the Image Quality and System Performance Conference 2016. DOI: https://doi.org/10.2352/ISSN.2470-1173.2016.13.IQSP-226
- “Cloud Resource Management for Image and Video Analysis of Big Data from Network Cameras”, International Conference on Cloud Computing and Big Data 2015. Pages: 287-294, DOI: https://doi.org/10.1109/CCBD.2015.8
- “Multimedia Content Creation using Global Network Cameras: The Making of CAM2”, IEEE Global Conference on Signal and Information Processing 2015. Pages: 15-18. DOI: https://doi.org/10.1109/GlobalSIP.2015.7416927

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Patents

- 11113344, “Automated Discovery of Network Camera in Heterogeneous Web Pages”
- 10904317, “System and Method for Identifying Publicly Available Cameras (1)”
- 10367877, “System and Method for Identifying Publicly Available Cameras (2)”
- 10506201, “Public Safety Camera Identification and Monitoring System and Method (1)”
- 10341617, “Public Safety Camera Identification and Monitoring System and Method (2)”