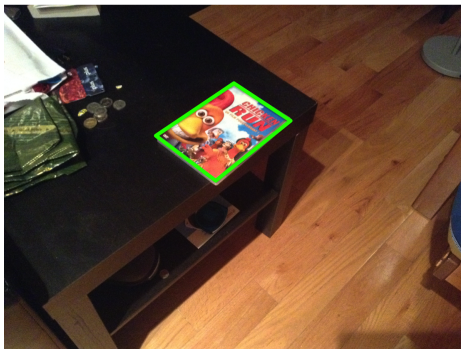


# Matching Planar Objects In New Viewpoints ... And Much More – via Homography

# What Transformation Happened To My DVD?

- Rectangle goes to a parallelogram





# Affine Transformations

Affine transformations are combinations of:

- Linear transformations, and
- Translations

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & b & e \\ c & d & f \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Properties of affine transformations:

- Origin does not necessarily map to origin
- Lines map to lines
- **Parallel lines remain parallel**
- Ratios are preserved
- Closed under composition
- Rectangles go to parallelograms

[Source: N. Snavely, slide credit: R. Urtasun]

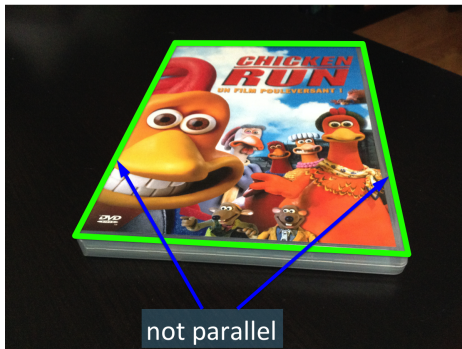
# What Transformation Really Happened To My DVD?

- What about now?

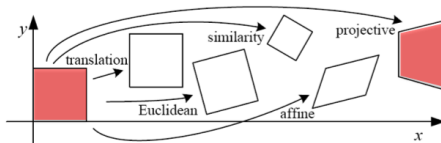







# What Transformation Really Happened To My DVD?

- Actually a rectangle goes to **quadrilateral**



# 2D Image Transformations



Transformation	Matrix	# DoF	Preserves	Icon
translation	$\begin{bmatrix} I & t \end{bmatrix}_{2 \times 3}$	2	orientation	
rigid (Euclidean)	$\begin{bmatrix} R & t \end{bmatrix}_{2 \times 3}$	3	lengths	
similarity	$\begin{bmatrix} sR & t \end{bmatrix}_{2 \times 3}$	4	angles	
affine	$\begin{bmatrix} A \end{bmatrix}_{2 \times 3}$	6	parallelism	
projective	$\begin{bmatrix} \tilde{H} \end{bmatrix}_{3 \times 3}$	8	straight lines	

- These transformations are a nested set of groups
- Closed under composition and inverse is a member

[source: R. Szeliski]

# Projective Transformations

- Homography:

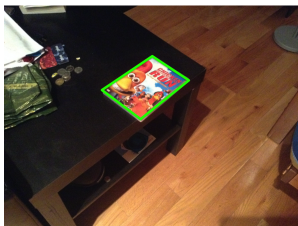
$$w \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Properties:

- Origin does not necessarily map to origin
- Lines map to lines
- **Parallel lines do not necessarily remain parallel**
- Ratios are **not** preserved
- Closed under composition
- Rectangle goes to quadrilateral
- Affine transformation is a special case, where  $g = h = 0$  and  $i = 1$

[Source: N. Snavely, slide credit: R. Urtasun]

# What Transformation Really Happened to My DVD?



For **planar** objects:

- Viewpoint change for planar objects is a **homography**
- Affine transformation **approximates** viewpoint change for planar objects that are far away from camera

# What Transformation Happened to My DVD?

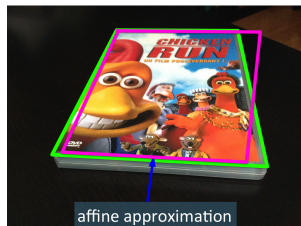
- Why should I care about homography?
- Now that I care, how should I estimate it?
- I want to understand the geometry behind homography. That is, why aren't parallel lines mapped to parallel lines in oblique viewpoints?  
How did we get that equation for computing the homography?

# Homography

- Why should I care about homography? **Let's answer this first**
- Now that I care, how should I estimate it?
- I want to understand the geometry behind homography. That is, why aren't parallel lines mapped to parallel lines in oblique viewpoints?  
How did we get that equation for computing the homography?



# Homography

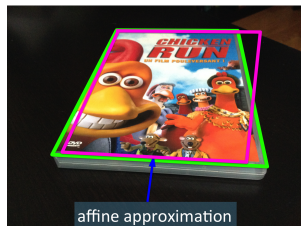


- Why do we need homography? Can't we just assume that the transformation is affine? The approximation on the right looks pretty decent to me...
- That's right. If I want to detect (match) an object in a new viewpoint, an affine transformation is a relatively decent approximation

# Homography

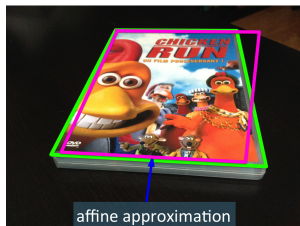
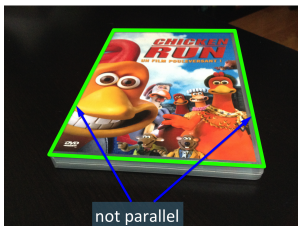


$T?$



- Why do we need homography? Can't we just assume that the transformation is affine? The approximation on the right looks pretty decent to me...
- That's right. If I want to detect (match) an object in a new viewpoint, an affine transformation is a relatively decent approximation
- But for some applications I want to be more accurate. Which?

# Homography



- Why do we need homography? Can't we just assume that the transformation is affine? The approximation on the right looks pretty decent to me...
- That's right. If I want to detect (match) an object in a new viewpoint, an affine transformation is a relatively decent approximation
- But for some applications I want to be more accurate. Which?

# Application 1: a Little Bit of CSI



- Tom Cruise is taking an exam on Monday

## Application 1: a Little Bit of CSI



exam is here

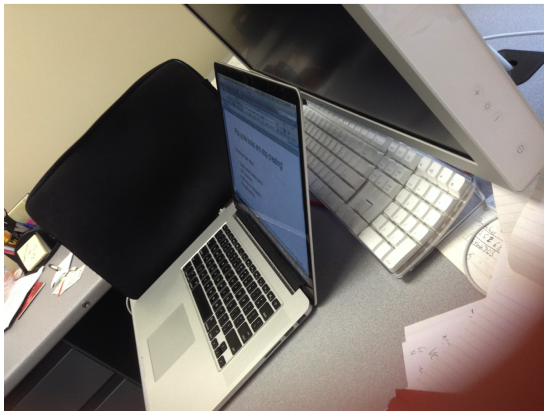
- The professor keeps the exams in this office

# Application 1: a Little Bit of CSI



- He enters (without permission) and takes a picture of the laptop screen

# Application 1: a Little Bit of CSI



- His picture turns out to not be from a viewpoint he was shooting for (it's difficult to take pictures while hanging)
- Can he still read the exam?

# Warping an Image with a Global Transformation



$\mathbf{p} = (x, y)$



$\mathbf{p}' = (x', y')$

- Transformation  $T$  is a coordinate-changing machine:

$$[x', y'] = T(x, y)$$

- What does it mean that  $T$  is global?
  - Is the same for any point  $\mathbf{p}$
  - Can be described by just a few numbers (parameters)

[Source: N. Snavely, slide credit: R. Urtasun]



# Warping an Image with a Global Transformation

- Example of warping for different transformations:



translation



rotation



aspect



affine



perspective

# Forward and Inverse Warping

- **Forward Warping:** Send each pixel  $f(x)$  to its corresponding location  $(x', y') = T(x, y)$  in  $g(x', y')$

```
procedure forwardWarp( $f, h$ , out  $g$ ):
```

For every pixel  $x$  in  $f(x)$

1. Compute the destination location  $x' = h(x)$ .
2. Copy the pixel  $f(x)$  to  $g(x')$ .

- **Inverse Warping:** Each pixel at destination is sampled from original image

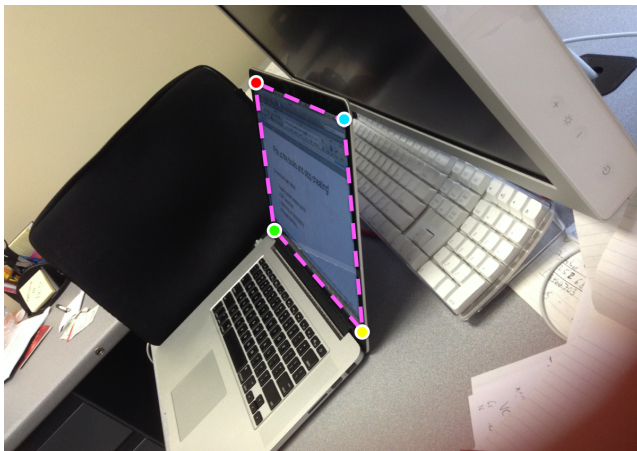
```
procedure inverseWarp( $f, h$ , out  $g$ ):
```

For every pixel  $x'$  in  $g(x')$

1. Compute the source location  $x = \hat{h}(x')$
2. Resample  $f(x)$  at location  $x$  and copy to  $g(x')$

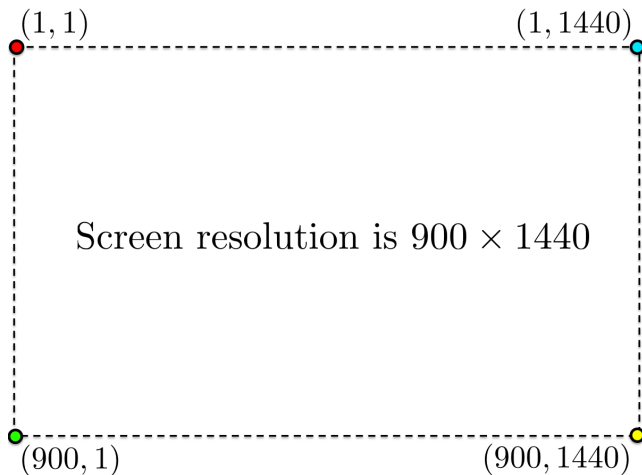
[source: R. Urtasun]

# Application 1: a Little Bit of CSI



- We want to transform the picture (plane) inside these 4 points into a rectangle (laptop screen)

## Application 1: a Little Bit of CSI

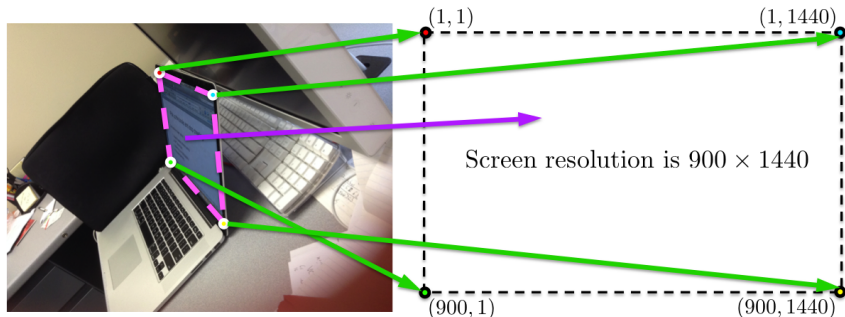


- We want it to look like this. How can we do this?

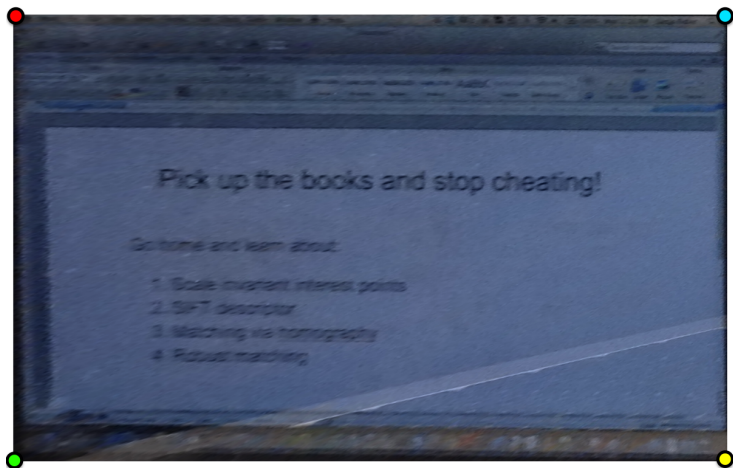
# Application 1: a Little Bit of CSI

- A transformation that maps a projective plane (a quadrilateral) to another projective plane (another quadrilateral, in this case a rectangle) is a homography

homography  $H$

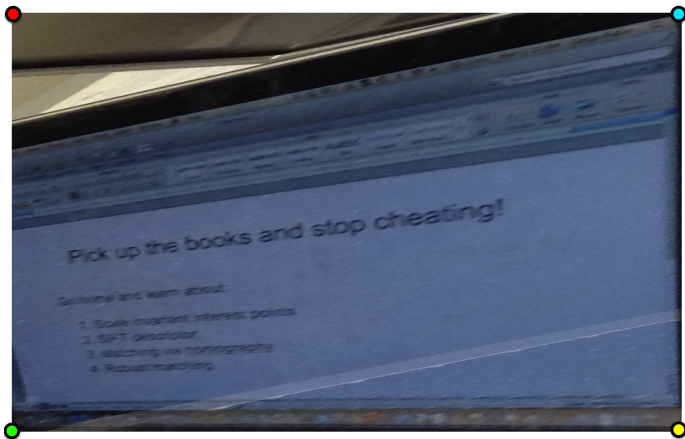


# Application 1: a Little Bit of CSI



- If we compute the homography and warp the image according to it, we get this

## Application 1: a Little Bit of CSI



- If we used affine transformation instead, we'd get this. Would be even worse if our picture was taken closer to the laptop

# Application 1: a Little More of CSI

What is the shape of the b/w floor pattern?



**Homography**



**The floor (enlarged)**

Slide from Antonio Criminisi



**Automatically  
rectified floor**

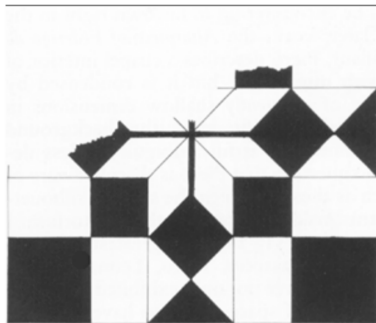


# Application 1: a Little More of CSI

Automatic rectification



Slide from Antonio Criminisi



From Martin Kemp *The Science of Art*  
(*manual reconstruction*)

# Application 1: a Little More of CSI



*St. Lucy Altarpiece, D. Veneziano*

Slide from Criminisi

What is the (complicated)  
shape of the floor pattern?



**Automatically rectified floor**

# Application 1: a Little More of CSI



**Automatic  
rectification**



**From Martin Kemp, *The Science of Art*  
(*manual reconstruction*)**

Slide from Criminisi

## Application 2: How Much do Soccer Players Run?

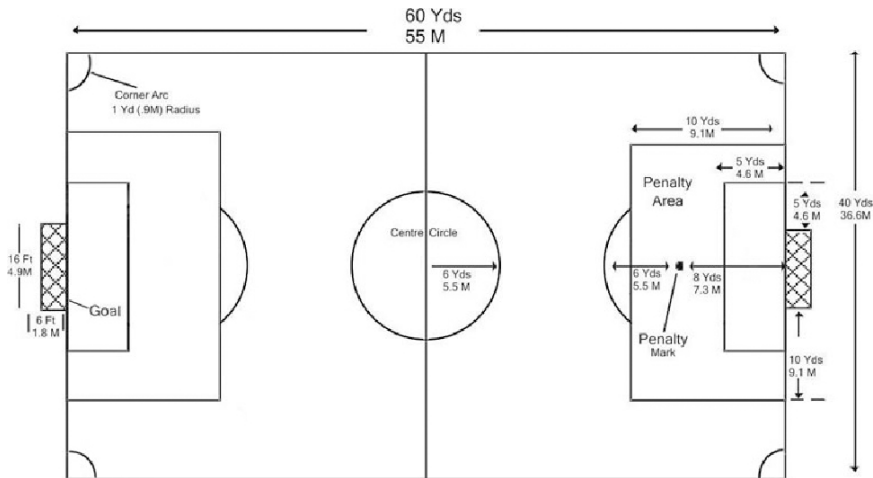


## Application 2: How Much do Soccer Players Run?



- How many meters did this player run?

## Application 2: How Much do Soccer Players Run?



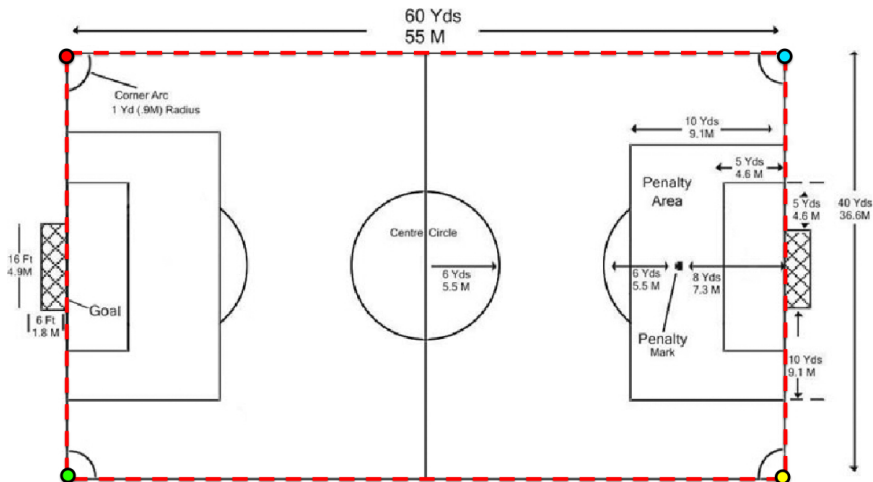
- Field is planar. We know its dimensions (look on Wikipedia).

## Application 2: How Much do Soccer Players Run?



- Let's take the 4 corner points of the field

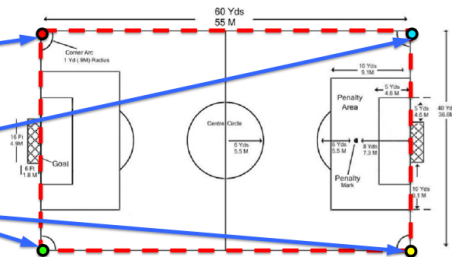
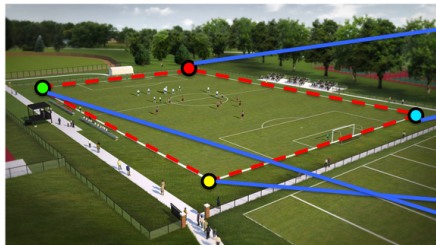
## Application 2: How Much do Soccer Players Run?



- We need to compute a homography that maps them to these 4 corners

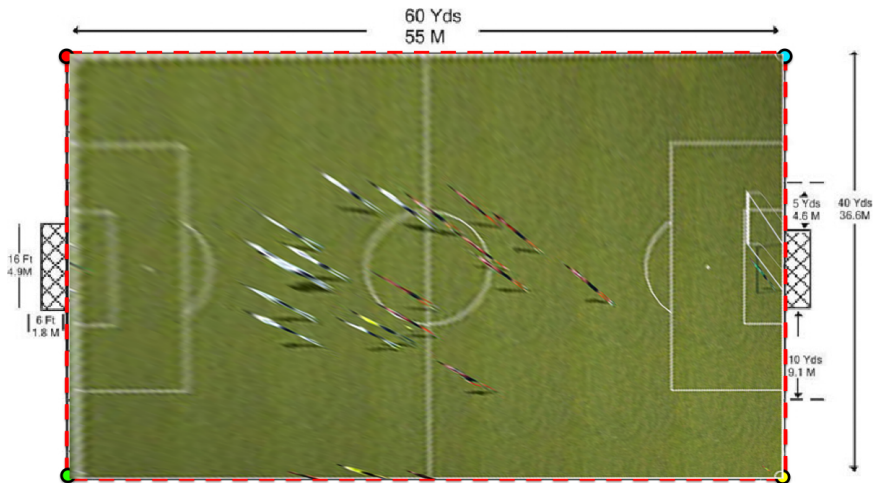


## Application 2: How Much do Soccer Players Run?



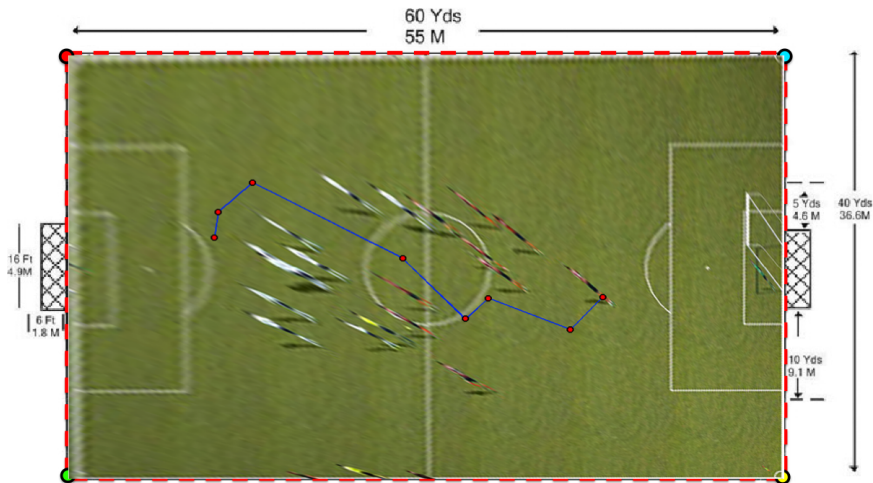
- We need to compute a homography that maps the 4 corners. Any other point from this plane (the field) also maps to the right with the same homography

## Application 2: How Much do Soccer Players Run?



- Nice. What happened to the players?

## Application 2: How Much do Soccer Players Run?



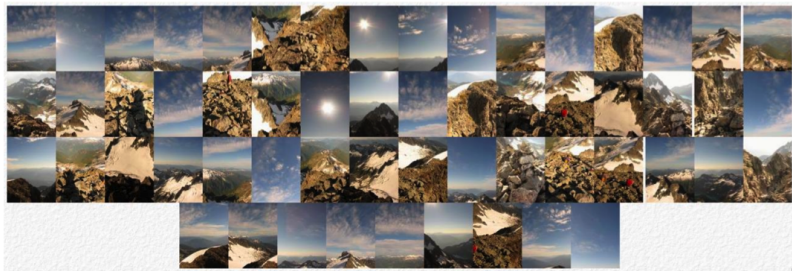
- We can now also transform the player's trajectory → and we have it in meters!

## Application 2: How Much do Soccer Players Run?



- If we used affine transformation... Our estimations of running would not be accurate!

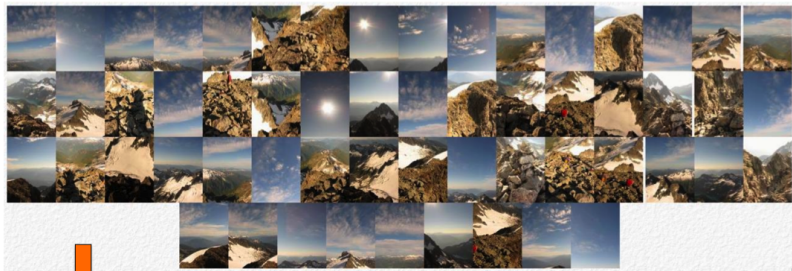
# Application 3: Panorama Stitching



Take a tripod, rotate camera  
and take pictures

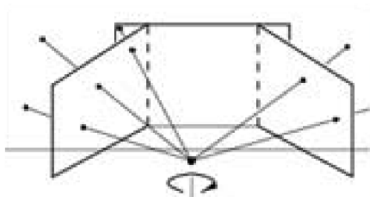
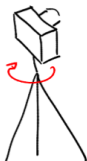
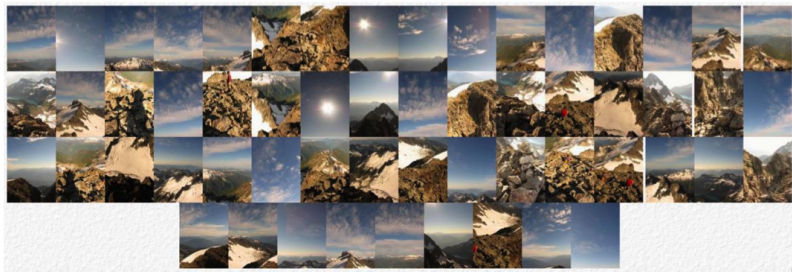
[Source: Fernando Flores-Mangas]

# Application 3: Panorama Stitching



[Source: Fernando Flores-Mangas]

# Application 3: Panorama Stitching



- Each pair of images is related by homography! **If we also moved the camera, this wouldn't be true (next class)** [Source: Fernando Flores-Mangas]

## Application 3: Panorama Stitching

- To do panorama stitching, we need to:
  - Match points between pairs of images  $I$  and  $J$
  - Compute a transformation between the between matches in  $I$  and  $J$  : a homography
  - Do it robustly (RANSAC)
  - Warp the first image to the second using the estimated homography
- Apart from the last point, this is exactly the same procedure as for the problem of matching planar objects across viewpoints
- So this should motivate the **why do I care part** of the homographies



# Homography

- Why should I care about homography?
- Now that I care, how should I estimate it? **Let's do this now**
- I want to understand the geometry behind homography. That is, why aren't parallel lines mapped to parallel lines in oblique viewpoints?  
How did we get that equation for computing the homography?

# Solving for Homographies

- Let  $(x_i, y_i)$  be a point on the reference (model) image, and  $(x'_i, y'_i)$  its match in the test image
- A homography  $H$  maps  $(x_i, y_i)$  to  $(x'_i, y'_i)$ :

$$\begin{bmatrix} ax'_i \\ ay'_i \\ a \end{bmatrix} = \begin{bmatrix} h_{00} & h_{01} & h_{02} \\ h_{10} & h_{11} & h_{12} \\ h_{20} & h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix}$$

# Solving for Homographies

- Let  $(x_i, y_i)$  be a point on the reference (model) image, and  $(x'_i, y'_i)$  its match in the test image
- A homography  $H$  maps  $(x_i, y_i)$  to  $(x'_i, y'_i)$ :

$$\begin{bmatrix} ax'_i \\ ay'_i \\ a \end{bmatrix} = \begin{bmatrix} h_{00} & h_{01} & h_{02} \\ h_{10} & h_{11} & h_{12} \\ h_{20} & h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix}$$

- We can get rid of that  $a$  on the left:

$$\begin{aligned} x'_i &= \frac{h_{00}x_i + h_{01}y_i + h_{02}}{h_{20}x_i + h_{21}y_i + h_{22}} \\ y'_i &= \frac{h_{10}x_i + h_{11}y_i + h_{12}}{h_{20}x_i + h_{21}y_i + h_{22}} \end{aligned}$$

# Solving for Homographies

- Let  $(x_i, y_i)$  be a point on the reference (model) image, and  $(x'_i, y'_i)$  its match in the test image
- A homography  $H$  maps  $(x_i, y_i)$  to  $(x'_i, y'_i)$ :

$$\begin{bmatrix} ax'_i \\ ay'_i \\ a \end{bmatrix} = \begin{bmatrix} h_{00} & h_{01} & h_{02} \\ h_{10} & h_{11} & h_{12} \\ h_{20} & h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix}$$

- We can get rid of that  $a$  on the left:

$$\begin{aligned} x'_i &= \frac{h_{00}x_i + h_{01}y_i + h_{02}}{h_{20}x_i + h_{21}y_i + h_{22}} \\ y'_i &= \frac{h_{10}x_i + h_{11}y_i + h_{12}}{h_{20}x_i + h_{21}y_i + h_{22}} \end{aligned}$$

- Hmmmm... Can I still rewrite this into a linear system in  $h$ ?

[Source: R. Urtasun]

# Solving for homographies

- From:

$$\begin{aligned}x'_i &= \frac{h_{00}x_i + h_{01}y_i + h_{02}}{h_{20}x_i + h_{21}y_i + h_{22}} \\y'_i &= \frac{h_{10}x_i + h_{11}y_i + h_{12}}{h_{20}x_i + h_{21}y_i + h_{22}}\end{aligned}$$

- We can easily get this:

$$\begin{aligned}x'_i (h_{20}x_i + h_{21}y_i + h_{22}) &= h_{00}x_i + h_{01}y_i + h_{02} \\y'_i (h_{20}x_i + h_{21}y_i + h_{22}) &= h_{10}x_i + h_{11}y_i + h_{12}\end{aligned}$$

- Rewriting it a little:

$$\begin{aligned}h_{00}x_i + h_{01}y_i + h_{02} - x'_i (h_{20}x_i + h_{21}y_i + h_{22}) &= 0 \\h_{10}x_i + h_{11}y_i + h_{12} - y'_i (h_{20}x_i + h_{21}y_i + h_{22}) &= 0\end{aligned}$$

# Solving for homographies

- We can re-write these equations:

$$h_{00}x_i + h_{01}y_i + h_{02} - x'_i (h_{20}x_i - h_{21}y_i - h_{22}) = 0$$

$$h_{10}x_i + h_{11}y_i + h_{12} - y'_i (h_{20}x_i - h_{21}y_i - h_{22}) = 0$$

- as a linear system!

$$\begin{bmatrix} x_i & y_i & 1 & 0 & 0 & 0 & -x'_i x_i & -x'_i y_i & -x'_i \\ 0 & 0 & 0 & x_i & y_i & 1 & -y'_i x_i & -y'_i y_i & -y'_i \end{bmatrix} \begin{bmatrix} h_{00} \\ h_{01} \\ h_{02} \\ h_{10} \\ h_{11} \\ h_{12} \\ h_{20} \\ h_{21} \\ h_{22} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

[Source: R. Urtasun]

# Solving for homographies

- Taking all our matches into account:

$$\begin{bmatrix}
 x_1 & y_1 & 1 & 0 & 0 & 0 & -x'_1 x_1 & -x'_1 y_1 & -x'_1 \\
 0 & 0 & 0 & x_1 & y_1 & 1 & -y'_1 x_1 & -y'_1 y_1 & -y'_1 \\
 & & & & & \vdots & & & \\
 x_n & y_n & 1 & 0 & 0 & 0 & -x'_n x_n & -x'_n y_n & -x'_n \\
 0 & 0 & 0 & x_n & y_n & 1 & -y'_n x_n & -y'_n y_n & -y'_n
 \end{bmatrix}
 \begin{bmatrix}
 h_{00} \\
 h_{01} \\
 h_{02} \\
 h_{10} \\
 h_{11} \\
 h_{12} \\
 h_{20} \\
 h_{21} \\
 h_{22}
 \end{bmatrix}
 =
 \begin{bmatrix}
 0 \\
 0 \\
 0 \\
 \vdots \\
 0 \\
 0 \\
 0 \\
 0 \\
 0
 \end{bmatrix}$$

**A**  
 $2n \times 9$

**h**  
 $9$

**0**  
 $2n$

# Solving for homographies

- Taking all our matches into account:

$$\begin{array}{c}
 \begin{bmatrix}
 x_1 & y_1 & 1 & 0 & 0 & 0 & -x'_1x_1 & -x'_1y_1 & -x'_1 \\
 0 & 0 & 0 & x_1 & y_1 & 1 & -y'_1x_1 & -y'_1y_1 & -y'_1 \\
 & & & & & \vdots & & & \\
 x_n & y_n & 1 & 0 & 0 & 0 & -x'_nx_n & -x'_ny_n & -x'_n \\
 0 & 0 & 0 & x_n & y_n & 1 & -y'_nx_n & -y'_ny_n & -y'_n
 \end{bmatrix}
 \begin{bmatrix}
 h_{00} \\
 h_{01} \\
 h_{02} \\
 h_{10} \\
 h_{11} \\
 h_{12} \\
 h_{20} \\
 h_{21} \\
 h_{22}
 \end{bmatrix}
 =
 \begin{bmatrix}
 0 \\
 0 \\
 \vdots \\
 0 \\
 0
 \end{bmatrix}
 \\
 \mathbf{A} \qquad \qquad \mathbf{h} \qquad \qquad \mathbf{0} \\
 2n \times 9 \qquad \qquad 9 \qquad \qquad 2n
 \end{array}$$

- How many matches do I need to estimate  $H$ ?
- This defines a least squares problem:

$$\min_{\mathbf{h}} ||\mathbf{Ah}||_2^2$$



# Solving for homographies

- Taking all our matches into account:

$$\begin{matrix}
 \begin{bmatrix}
 x_1 & y_1 & 1 & 0 & 0 & 0 & -x'_1x_1 & -x'_1y_1 & -x'_1 \\
 0 & 0 & 0 & x_1 & y_1 & 1 & -y'_1x_1 & -y'_1y_1 & -y'_1 \\
 & & & & & \vdots & & & \\
 x_n & y_n & 1 & 0 & 0 & 0 & -x'_nx_n & -x'_ny_n & -x'_n \\
 0 & 0 & 0 & x_n & y_n & 1 & -y'_nx_n & -y'_ny_n & -y'_n
 \end{bmatrix}
 &
 \begin{bmatrix}
 h_{00} \\
 h_{01} \\
 h_{02} \\
 h_{10} \\
 h_{11} \\
 h_{12} \\
 h_{20} \\
 h_{21} \\
 h_{22}
 \end{bmatrix}
 &
 =
 &
 \begin{bmatrix}
 0 \\
 0 \\
 0 \\
 \vdots \\
 0 \\
 0 \\
 0
 \end{bmatrix}
 \\
 \mathbf{A}_{2n \times 9} & \mathbf{h}_9 & \mathbf{0}_{2n}
 \end{matrix}$$

- How many matches do I need to estimate  $H$ ?
- This defines a least squares problem:

$$\min_{\mathbf{h}} \|\mathbf{Ah}\|_2^2$$

- Since  $\mathbf{h}$  is only defined up to scale, solve for unit vector

# Solving for homographies

- Taking all our matches into account:

$$\begin{matrix}
 \begin{bmatrix}
 x_1 & y_1 & 1 & 0 & 0 & 0 & -x'_1x_1 & -x'_1y_1 & -x'_1 \\
 0 & 0 & 0 & x_1 & y_1 & 1 & -y'_1x_1 & -y'_1y_1 & -y'_1 \\
 & & & & & \vdots & & & \\
 x_n & y_n & 1 & 0 & 0 & 0 & -x'_nx_n & -x'_ny_n & -x'_n \\
 0 & 0 & 0 & x_n & y_n & 1 & -y'_nx_n & -y'_ny_n & -y'_n
 \end{bmatrix}
 &
 \begin{bmatrix}
 h_{00} \\
 h_{01} \\
 h_{02} \\
 h_{10} \\
 h_{11} \\
 h_{12} \\
 h_{20} \\
 h_{21} \\
 h_{22}
 \end{bmatrix}
 &
 =
 &
 \begin{bmatrix}
 0 \\
 0 \\
 0 \\
 \vdots \\
 0 \\
 0 \\
 0
 \end{bmatrix}
 \\
 \mathbf{A}_{2n \times 9}
 &
 \mathbf{h}_9
 &
 \mathbf{0}_{2n}
 \end{matrix}$$

- How many matches do I need to estimate  $H$ ?
- This defines a least squares problem:

$$\min_{\mathbf{h}} \|\mathbf{A}\mathbf{h}\|_2^2$$

- Since  $\mathbf{h}$  is only defined up to scale, solve for unit vector
- Solution:  $\hat{\mathbf{h}}$  = eigenvector of  $\mathbf{A}^T\mathbf{A}$  with smallest eigenvalue

# Solving for homographies

- Taking all our matches into account:

$$\begin{matrix}
 \begin{bmatrix}
 x_1 & y_1 & 1 & 0 & 0 & 0 & -x'_1x_1 & -x'_1y_1 & -x'_1 \\
 0 & 0 & 0 & x_1 & y_1 & 1 & -y'_1x_1 & -y'_1y_1 & -y'_1 \\
 & & & & & \vdots & & & \\
 x_n & y_n & 1 & 0 & 0 & 0 & -x'_nx_n & -x'_ny_n & -x'_n \\
 0 & 0 & 0 & x_n & y_n & 1 & -y'_nx_n & -y'_ny_n & -y'_n
 \end{bmatrix} &
 \begin{bmatrix}
 h_{00} \\
 h_{01} \\
 h_{02} \\
 h_{10} \\
 h_{11} \\
 h_{12} \\
 h_{20} \\
 h_{21} \\
 h_{22}
 \end{bmatrix} &
 = &
 \begin{bmatrix}
 0 \\
 0 \\
 0 \\
 0 \\
 0 \\
 0 \\
 0 \\
 0 \\
 0
 \end{bmatrix} \\
 \mathbf{A}_{2n \times 9} & \mathbf{h}_9 & \mathbf{0}_{2n}
 \end{matrix}$$

- How many matches do I need to estimate  $H$ ?
- This defines a least squares problem:

$$\min_{\mathbf{h}} \|\mathbf{A}\mathbf{h}\|_2^2$$

- Since  $\mathbf{h}$  is only defined up to scale, solve for unit vector
- Solution:  $\hat{\mathbf{h}}$  = eigenvector of  $\mathbf{A}^T\mathbf{A}$  with smallest eigenvalue
- Works with 4 or more points

[Source: R. Urtasun]

# Image Alignment Algorithm: Homography

Given images  $I$  and  $J$

- 1 Compute image features for  $I$  and  $J$
- 2 Match features between  $I$  and  $J$
- 3 Compute **homography** transformation  $A$  between  $I$  and  $J$  (with RANSAC)

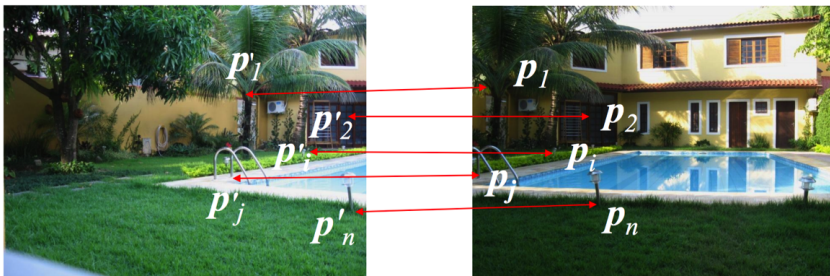
# Image Alignment Algorithm: Homography

Given images  $I$  and  $J$

- 1 Compute image features for  $I$  and  $J$
- 2 Match features between  $I$  and  $J$
- 3 Compute **homography** transformation  $A$  between  $I$  and  $J$  (with RANSAC)

[Source: N. Snavely]

# Panorama Stitching: Example 1



- Compute the matches

[Source: R. Queiroz Feitosa]

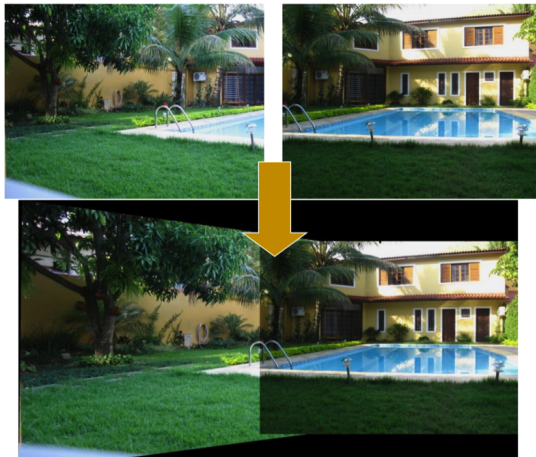
# Panorama Stitching: Example 1



- Estimate the homography and warp

[Source: R. Queiroz Feitosa]

# Panorama Stitching: Example 1

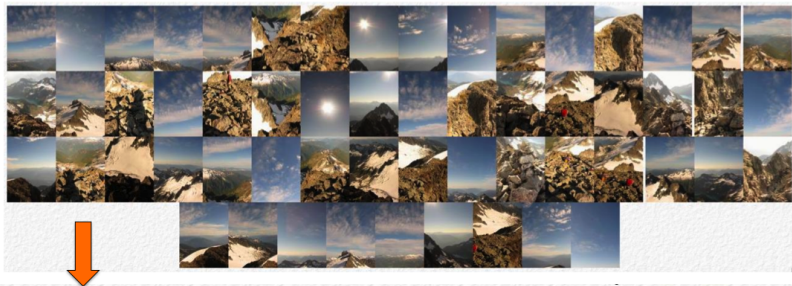


- Stitch

[Source: R. Queiroz Feitosa]

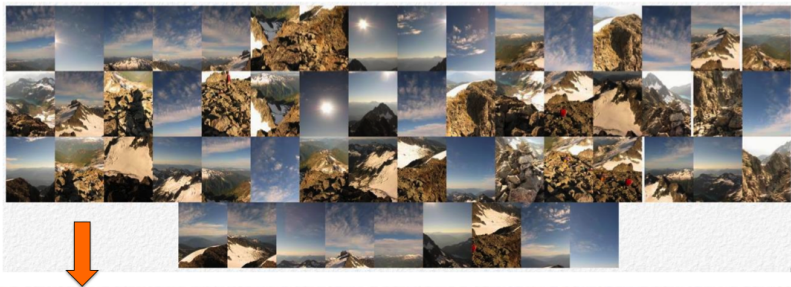


# Panorama Stitching: Example 2



[Source: Fernando Flores-Mangas]

# Panorama Stitching: Example 2



[Source: Fernando Flores-Mangas]

# Panorama Stitching: Example 2



Laplacian Pyramid Blending  $\Downarrow$  seams not visible anymore



(Brown & Lowe; ICCV 2003) google "Lowe Brown Autostitch"

[Source: Fernando Flores-Mangas]

# Summary – Stuff You Need To Know

- A homography is a mapping between projective planes
- You need at least 4 correspondences (matches) to compute it

## Matlab functions:

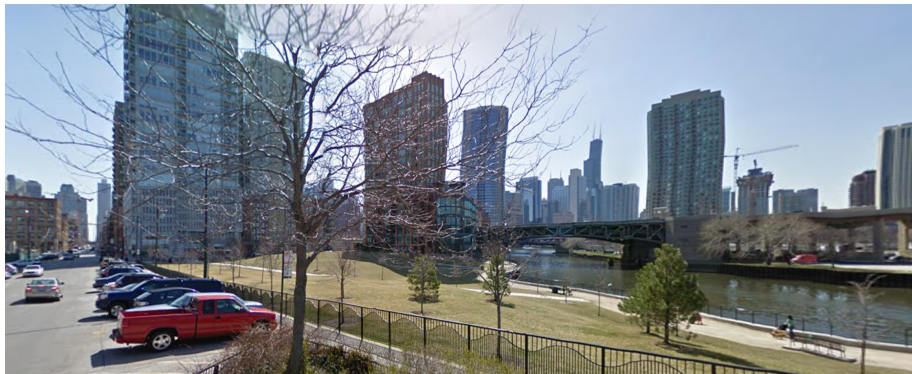
- `TFORM = MAKETFORM('AFFINE',[x1,y1],[x2,y2]);` % Computes affine transformation between points  $[x_1, y_1]$  and  $[x_2, y_2]$ . Needs 3 pairs of matches ( $x_1, y_1, x_2, y_2$  have three rows)
- `TFORM = MAKETFORM('PROJECTIVE',[x1,y1],[x2,y2]);` % Computes homography between points  $[x_1, y_1]$  and  $[x_2, y_2]$ . Needs 4 pairs of matches
- `IMW = IMTRANSFORM(IM, TFORM, 'BICUBIC','FILL', 0);` % Warps the image according to transformation

# Birdseye View on What We Learned So Far

<b>Problem</b>	<b>Detection</b>	<b>Description</b>	<b>Matching</b>
Find Planar Distinctive Objects	Scale Invariant Interest Points	Local feature: SIFT	All features to all features + Affine / Homography
Panorama Stitching	Scale Invariant Interest Points	Local feature: SIFT	All features to all features + Homography

# Exercise: How Dangerous is This Street?

- Can I walk here during the night? Can we tell this from an image?



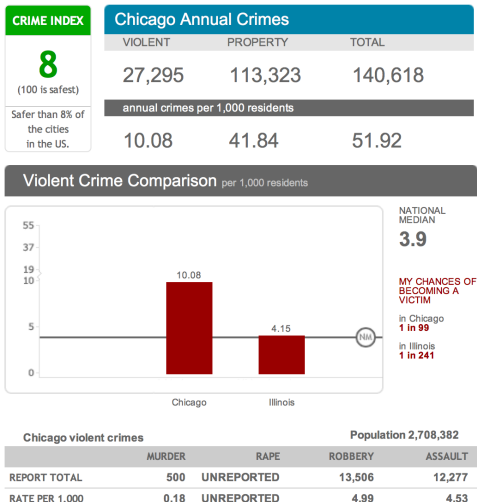
# Exercise: How Dangerous is This Street?

- Can I walk here during the night? Can we tell this from an image?



# Exercise: How Dangerous is This Street?

- It's Chicago...

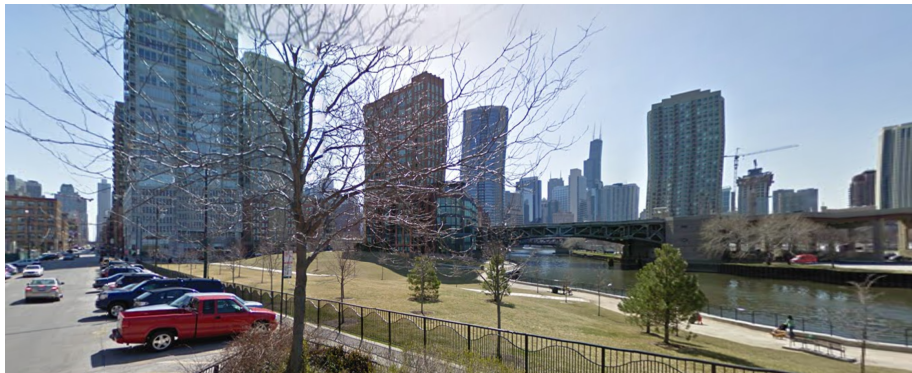


<http://www.neighborhoodscout.com/il/chicago/crime/>

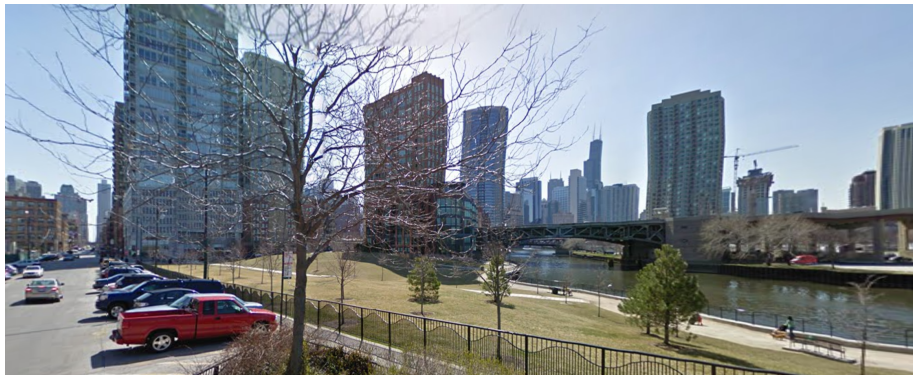


# Exercise: How Dangerous is This Street?

- It's Chicago... Can I walk here during the day?



# Exercise: How Dangerous is This Street?



- Idea: Match image to Google's StreetView images of Chicago!

# Exercise: How Dangerous is This Street?

## • Our match to StreetView



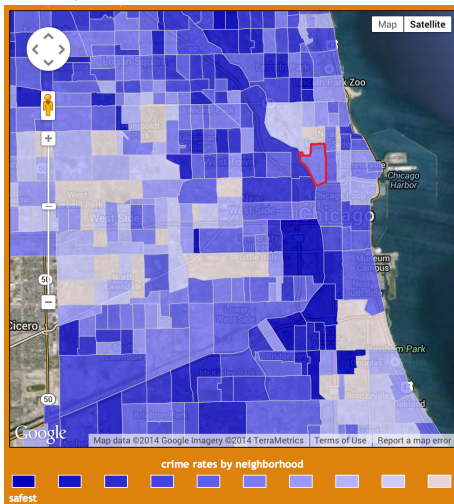
# Exercise: How Dangerous is This Street?

- Lookup the GPS location...



# Exercise: How Dangerous is This Street?

- Lookup the crime map for that GPS location



<http://www.neighborhoodscout.com/il/chicago/crime/>

# Exercise: How Dangerous is This Street?

- Lookup the crime map for that GPS location



<http://www.neighborhoodscout.com/il/chicago/crime/>

- We're in 2019...

Think not (only) what you can do with one image, but what **lots and lots** of images can do for you

- We're in 2019...

Think not (only) what you can do with one image, but what **lots and lots** of images can do for you

- Would our current matching method work with lots of data?



- So far we matched a known object in a new viewpoint
- What if we have to match an object to **LOTS** of images? Or **LOTS** of objects to one image?
- Please read this and we will discuss:

Josef Sivic, Andrew Zisserman

*Video Google: A Text Retrieval Approach to Object Matching in Videos*

ICCV 2003

Paper link: <http://www.robots.ox.ac.uk/~vgg/publications/papers/sivic03.pdf>

# Next Time: Camera Models