

Applications

Presented by

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Most slides Courtesy to the papers' authors

Photo Tourism: Exploring Photo Collections in 3D

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Steven M. Seitz

University of Washington

Richard Szeliski

Microsoft Research



15,464



37,383



76,389

Google Demo

The goal of Photo Tourism is to use location information to build a better visualization and photo exploration tool for collections of photos of the same scene.

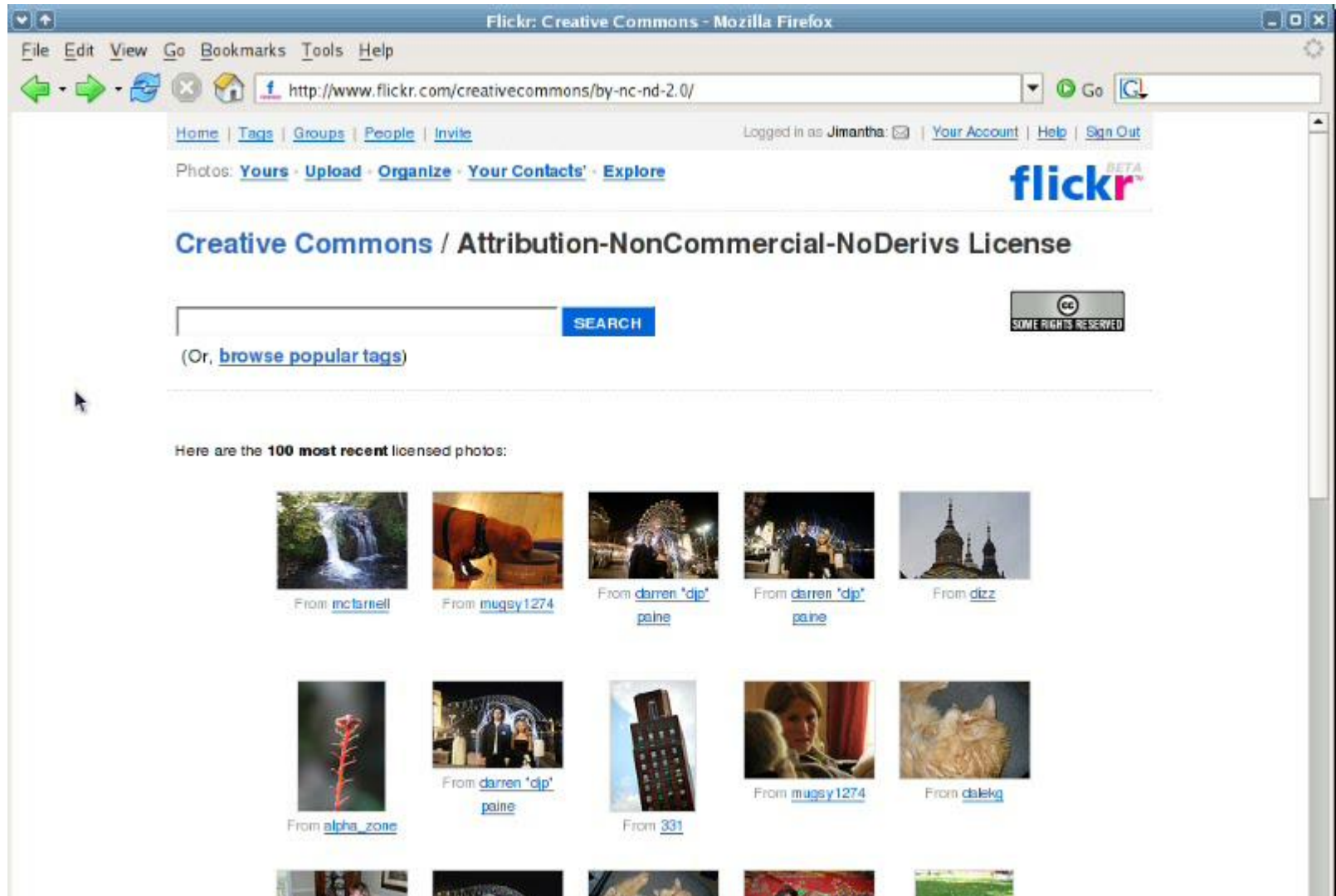
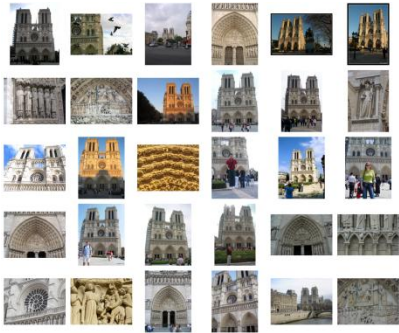


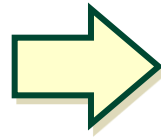
Photo Tourism

- A demo
- The system takes the set of photos and automatically determines the relative positions and orientations from which each photo was taken.
- We can then load the photos into the immersive 3D browser where the user can visualize and explore the photos using spatial relationships.

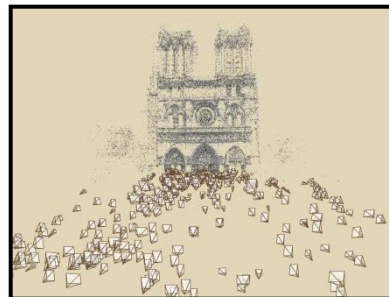
Photo Tourism overview



Input photographs
-Internet
-Personal collection



Scene
geometry
reconstruction



- Relative camera positions and orientations
- Point cloud for scene geometry
- Sparse correspondence

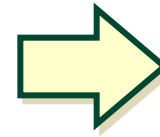


Photo
Explorer

Related work

- Image-based modeling (recover scene geometry)



Debevec, *et al.*
SIGGRAPH 1996



Schaffalitzky and Zisserman
ECCV 2002



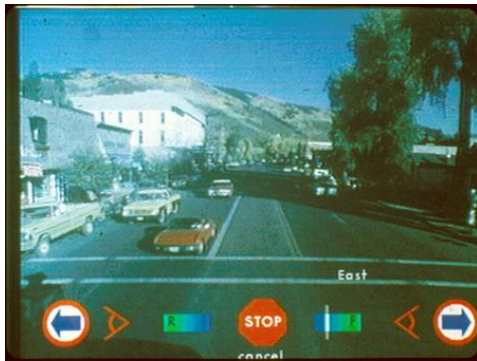
Brown and Lowe
3DIM 2005

automatic structure from motion on unordered sets of images

However, this modeling system is the first to be successfully applied to hundreds of images taken from the Internet.

Related work

- Image-based rendering (depict transitions between images)



Aspen Movie Map
Lippman, *et al.*, 1978

Photorealistic IBR:

Levoy and Hanrahan, SIGGRAPH 1996

Gortler, *et al*, SIGGRAPH 1996

Seitz and Dyer, SIGGRAPH 1996

Aliaga, *et al*, SIGGRAPH 2001

and many others

They created an interactive virtual tour of the city of Aspen,

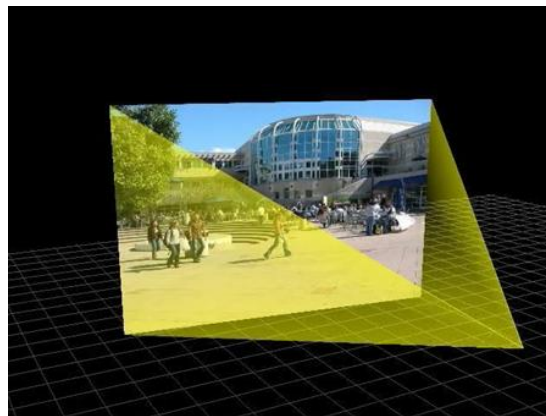
Same exploration features, but which required extensive manual effort to create.

Related work

- Image browsing and image retrieval



WWMX
Toyama, *et al*,
Int. Conf. Multimedia, 2003
Use location information to
organize photos,
No immersive browsing
experience

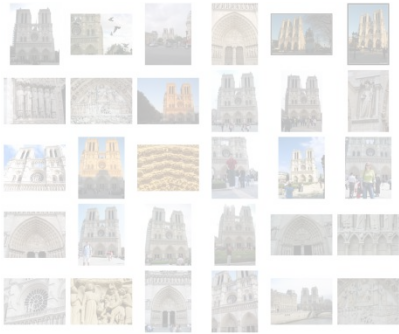


The Realityflythrough
project
McCurdy and Griswold
Mobisys 2003
Use GPS to locate
images in space
PhotoTourism system
don't use GPS

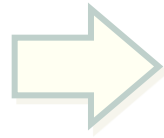


Video Google
Sivic and Zisserman
ICCV 2003
It allow users to find
objects in videos by
selecting them.
PT: "3D photo browser"
context

Photo Tourism overview



Input photographs



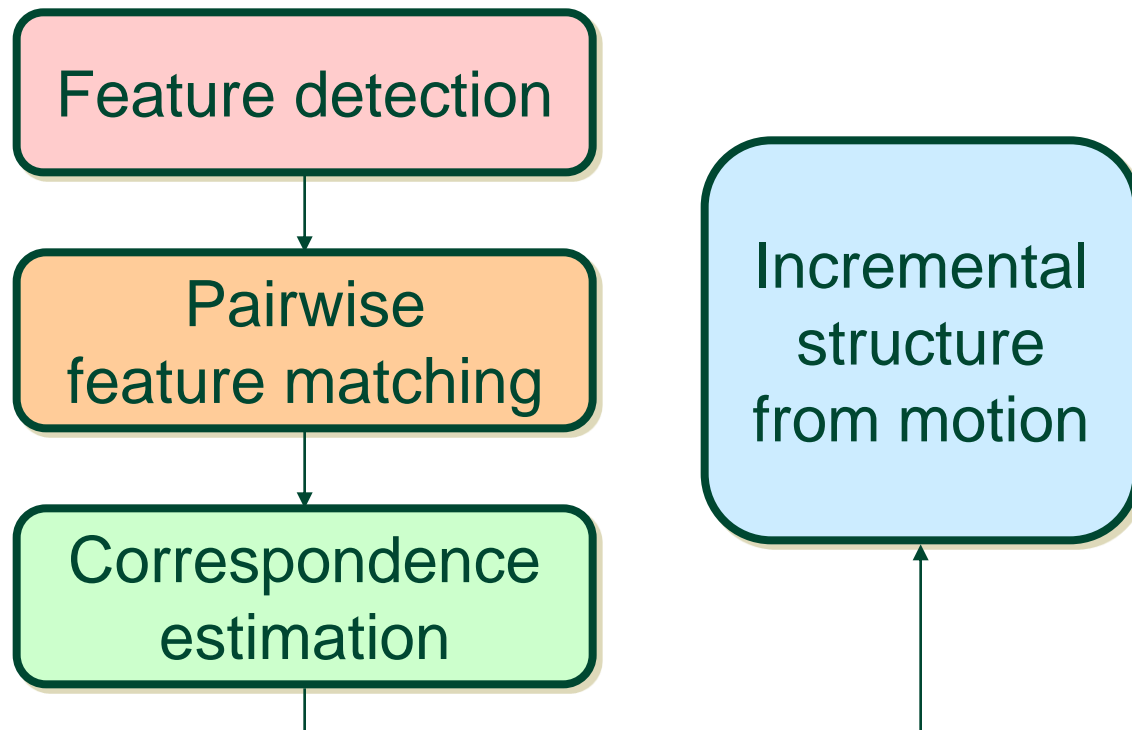
Scene
reconstruction



Photo
Explorer

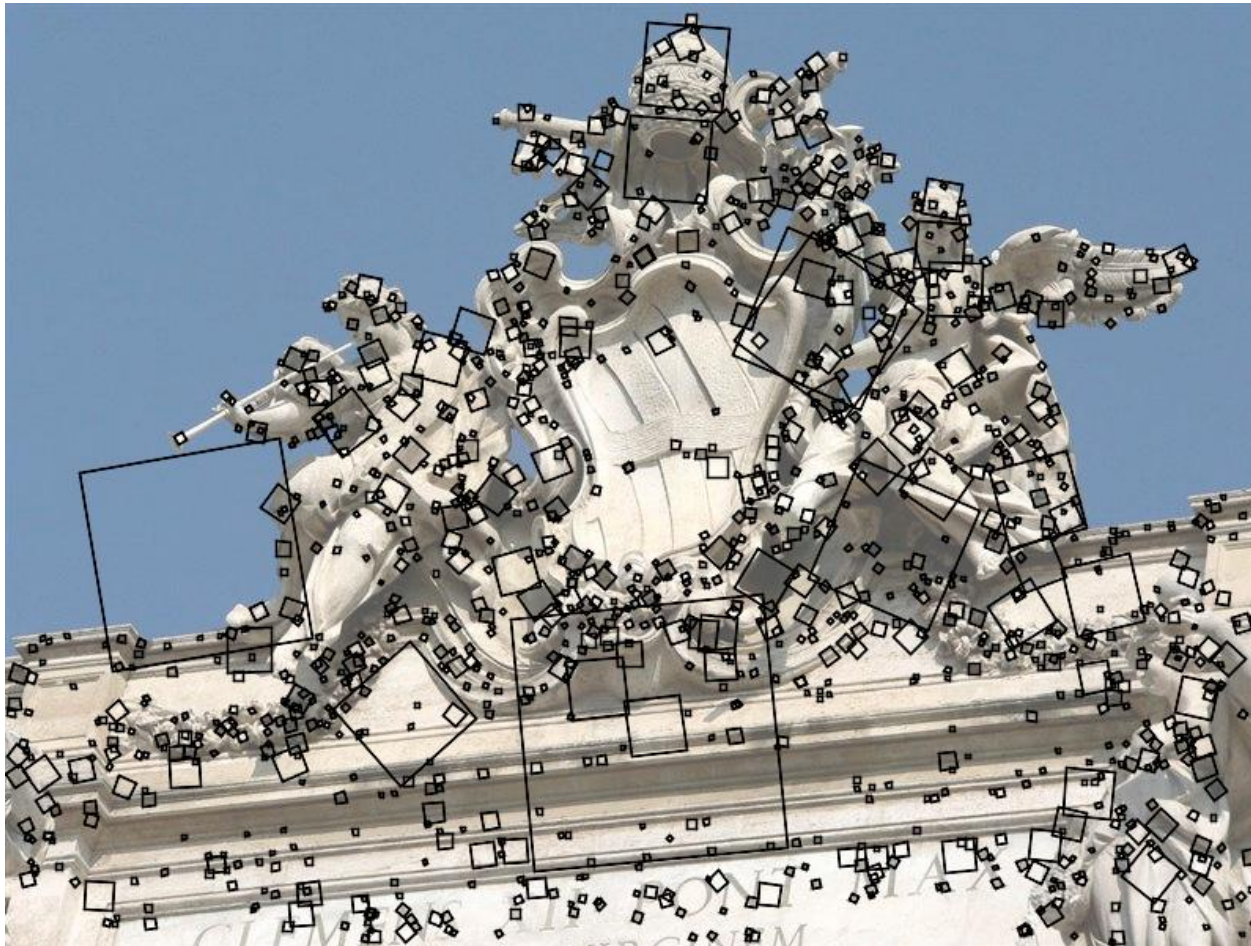
Scene reconstruction

- Automatically estimate
 - position, orientation, and focal length of cameras (i.e. zoom)
 - 3D positions of feature points



Feature detection

Detect features using SIFT [Lowe, IJCV 2004]



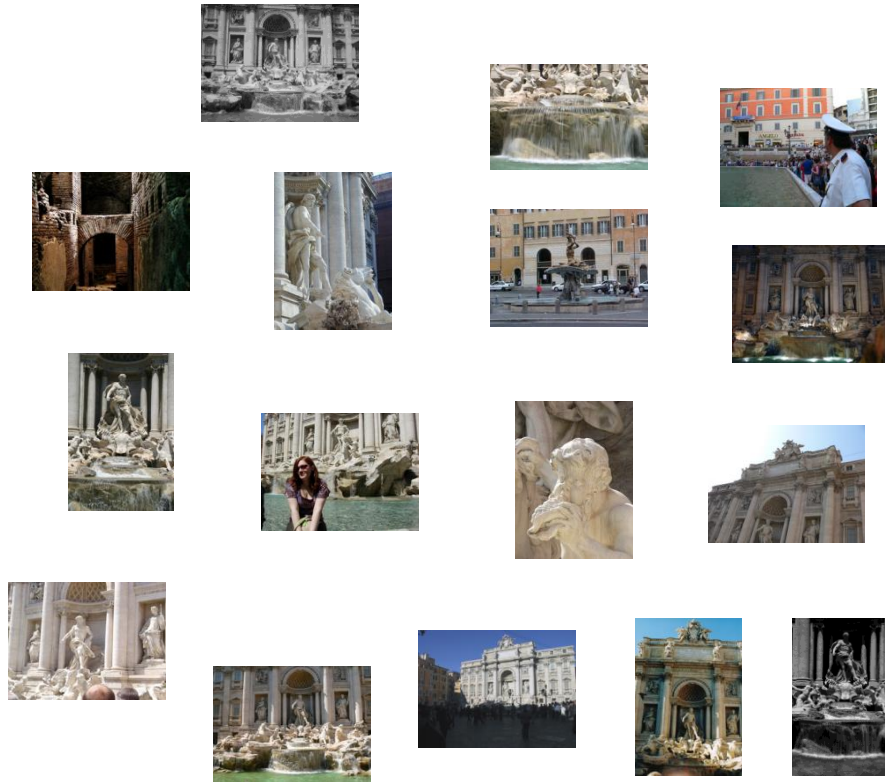
invariant to
-scale
-Rotation
- affine changes in image intensity.

squares are scaled and rotated to reflect the scale and orientation of the features

The Trevi Fountain

Feature detection

Detect features using SIFT [Lowe, IJCV 2004]



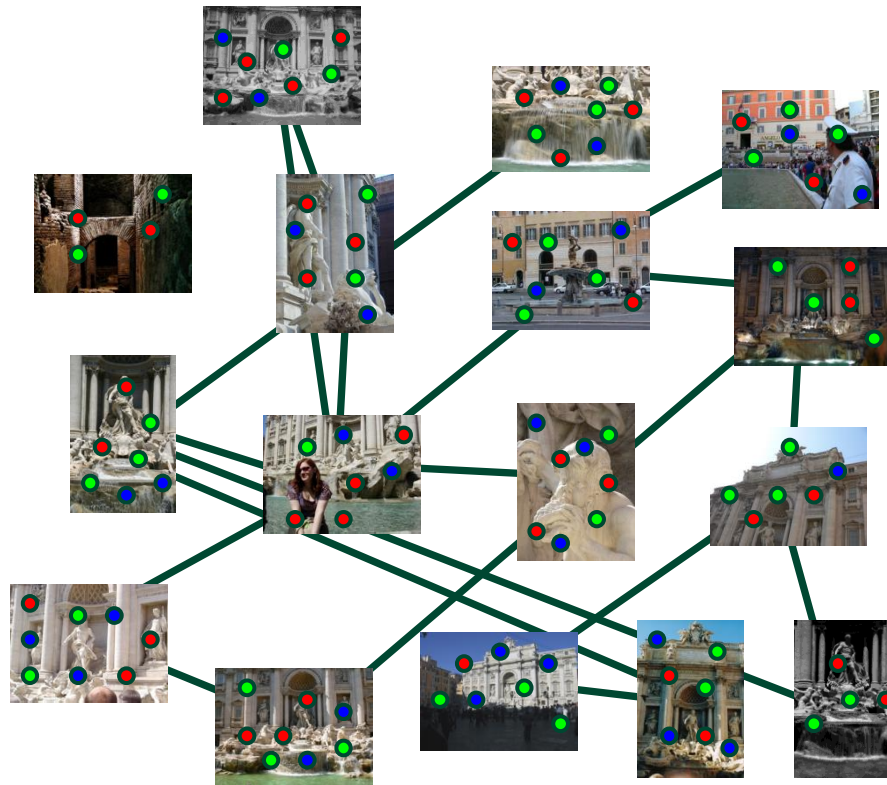
Feature detection

Detect features using SIFT [Lowe, IJCV 2004]



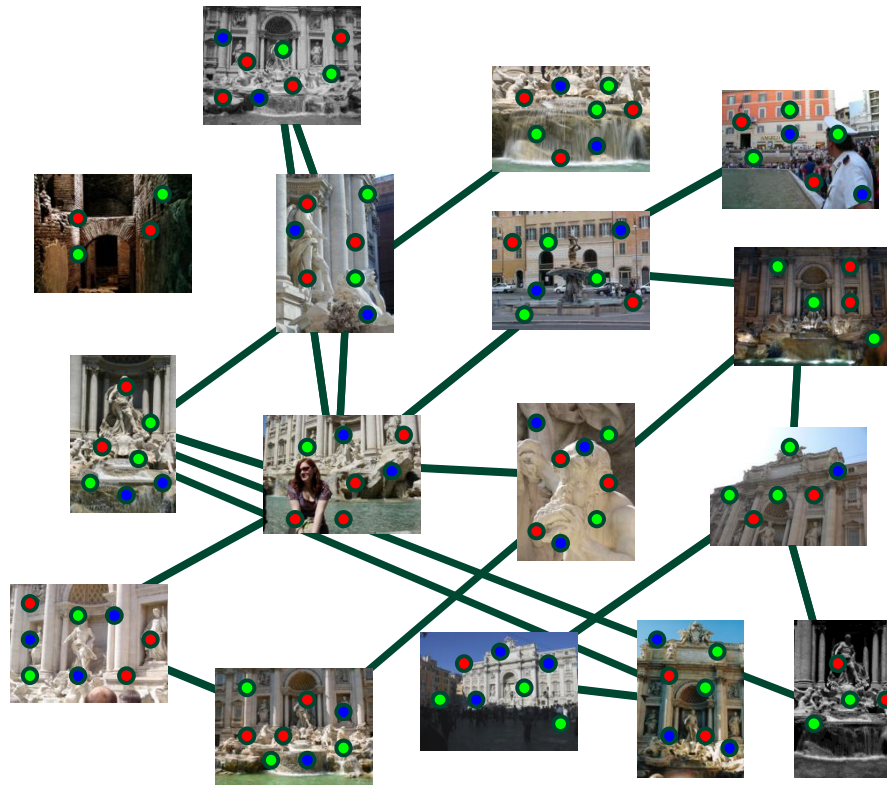
Feature matching

Match features between each pair of images

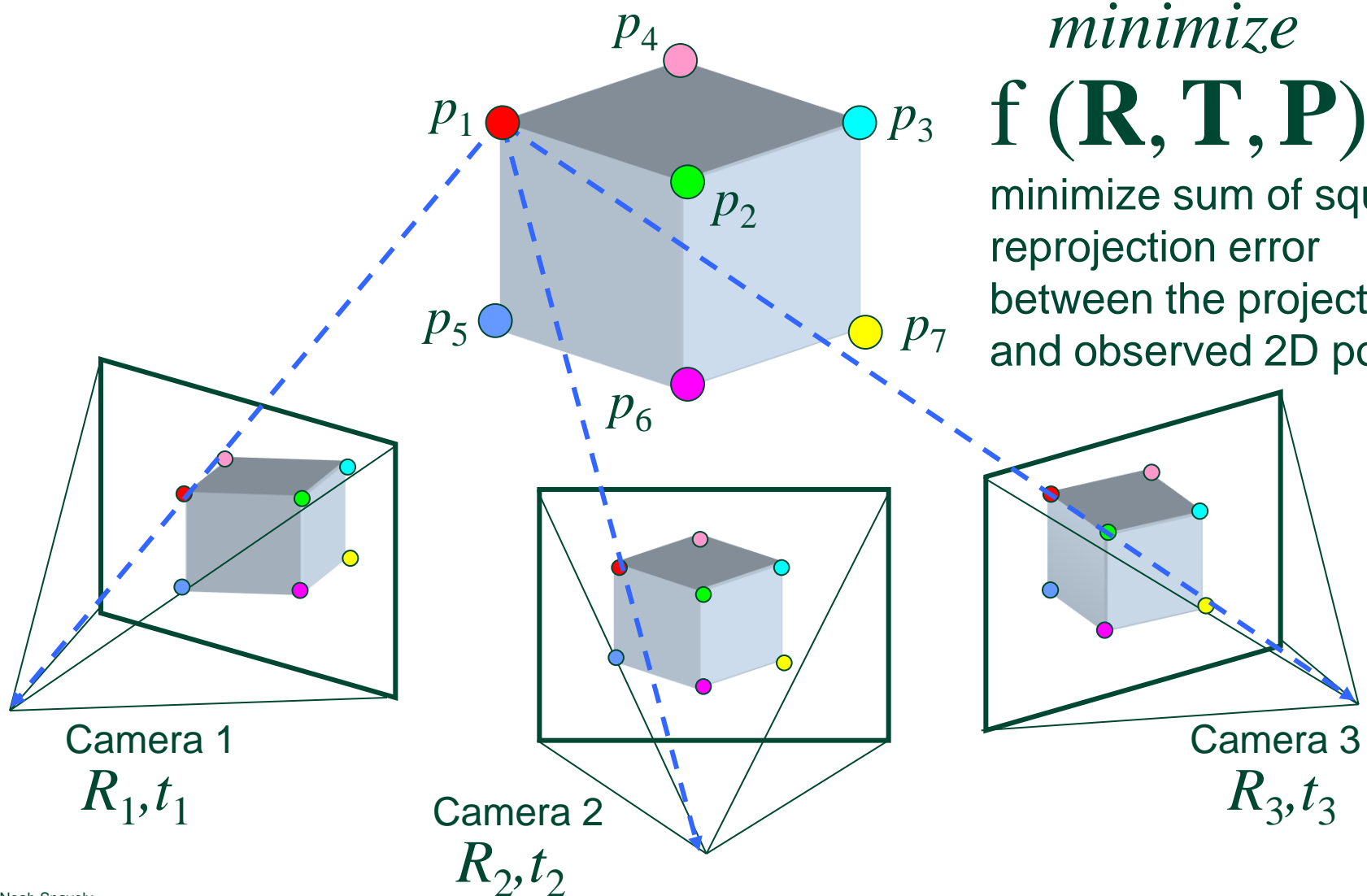


Feature matching

Refine matching using RANSAC [Fischler & Bolles 1987] to estimate fundamental matrices between pairs and then keep only matches consistent with that fundamental matrix.



Structure from motion



Structure from motion (Cont.)

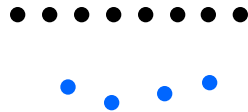
- This is a non-linear least squares problem and can be solved with algorithms such as Levenberg-Marquart.
- However, because the problem is non-linear, it can be sensitive to local minima.
- Therefore, it's important to initialize the parameters of the system carefully.
- In addition, we need to be able to deal with erroneous correspondences.

Incremental structure from motion

reconstruct the scene incrementally

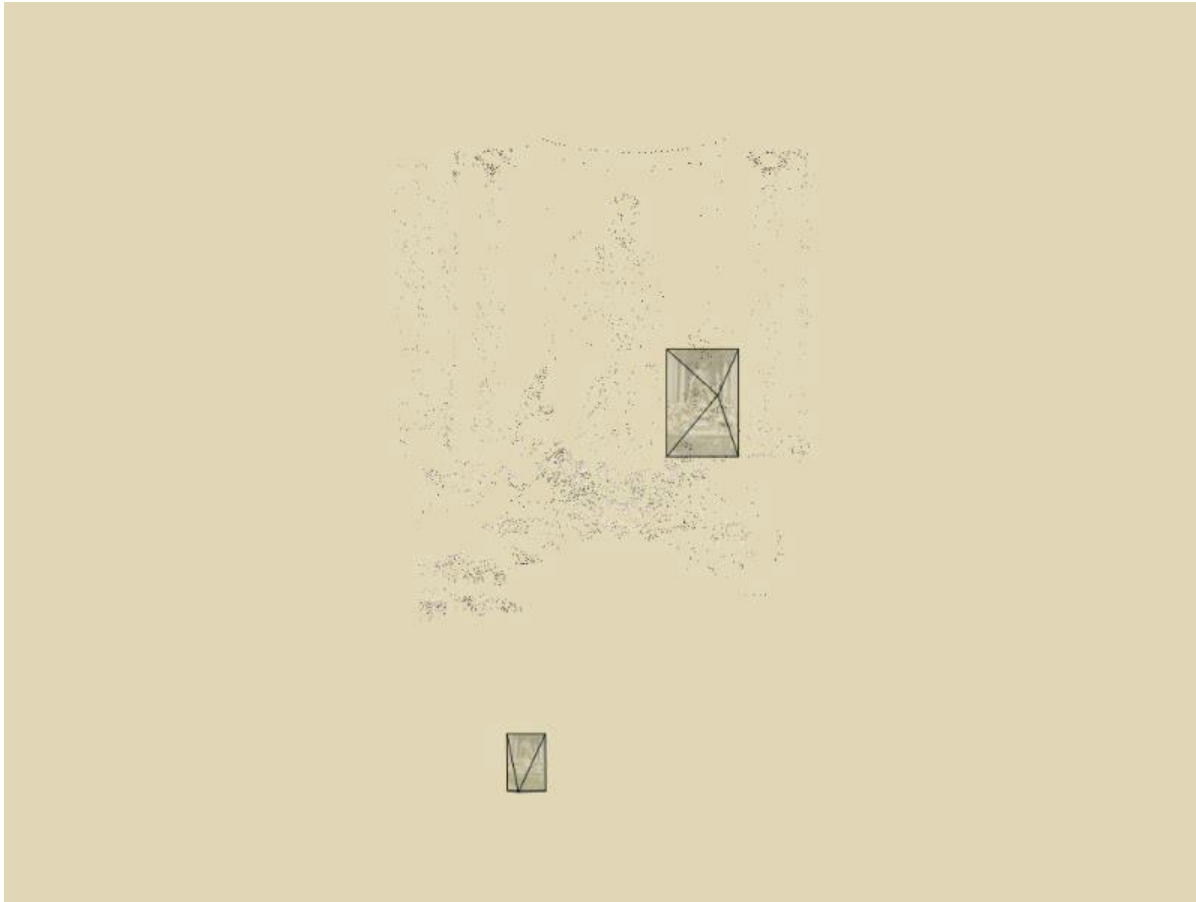


Incremental structure from motion



Incremental structure from motion

Demo 1



Incremental structure from motion

Demo 2

repeat until no more photos match any points in the scene

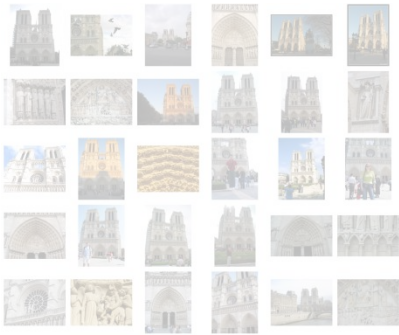
Reconstruction performance

- For photo sets from the Internet, 20% to 75% of the photos were registered
- Most unregistered photos belonged to different connected components (e.g. when searching for the Notre Dame cathedral, you get back photos of both the interior and exterior)
- Some failure cases (noisy, dark, too low resolution, too different angle than others)

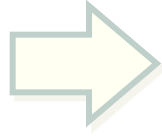


- Running time: < 1 hour for 80 photos
> 1 week for 2600 photo

Photo Tourism overview



Input photographs

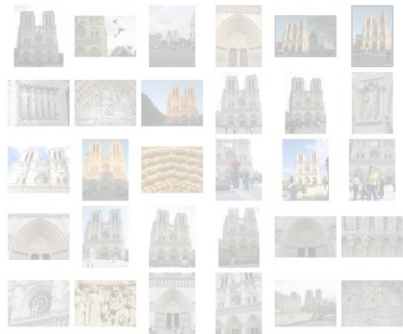


Scene
reconstruction

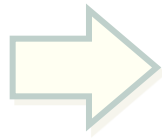


Photo
Explorer

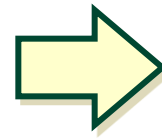
Photo Tourism overview



Input photographs



Scene
reconstruction

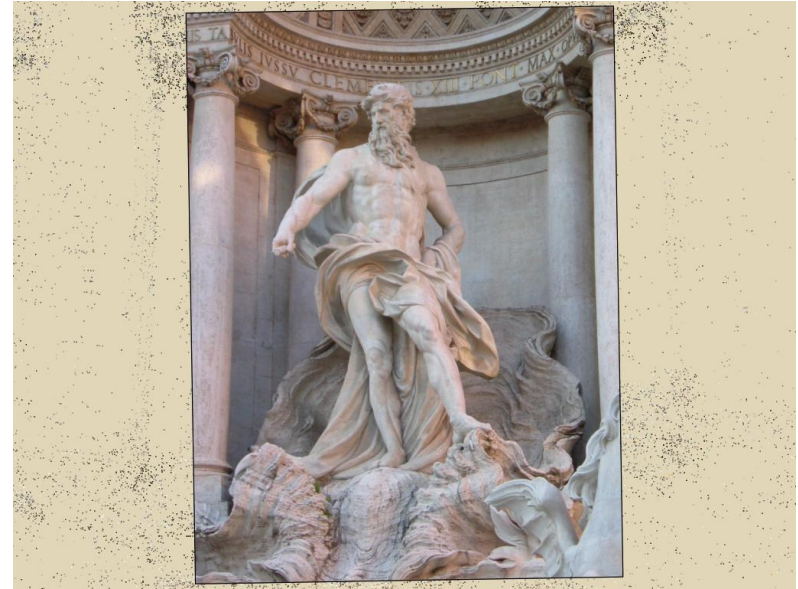


- Navigation
- Rendering
- Annotations

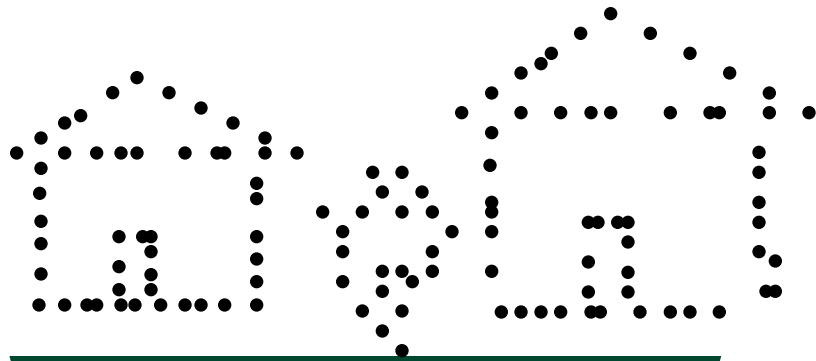
Navigation controls

- Free-flight navigation
- Object-based browsing
- Relation-based browsing
- Overhead map

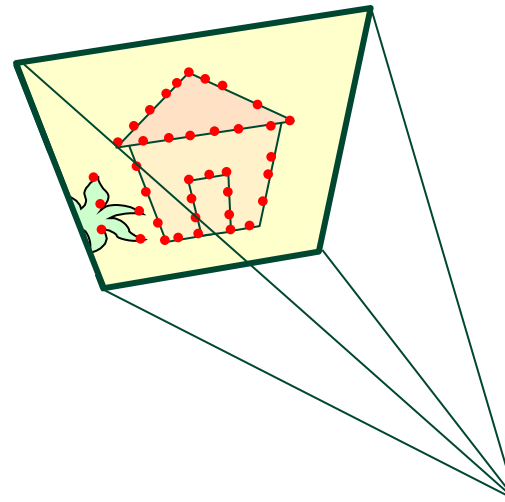
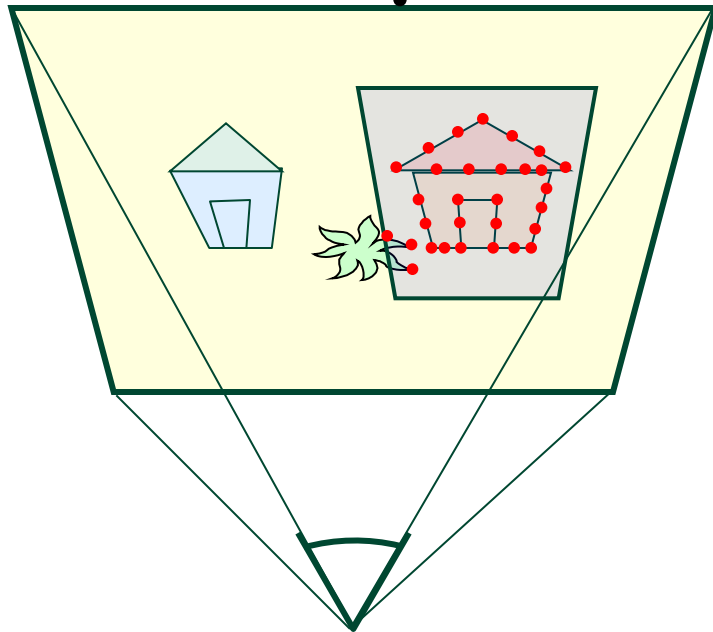
Object-based browsing



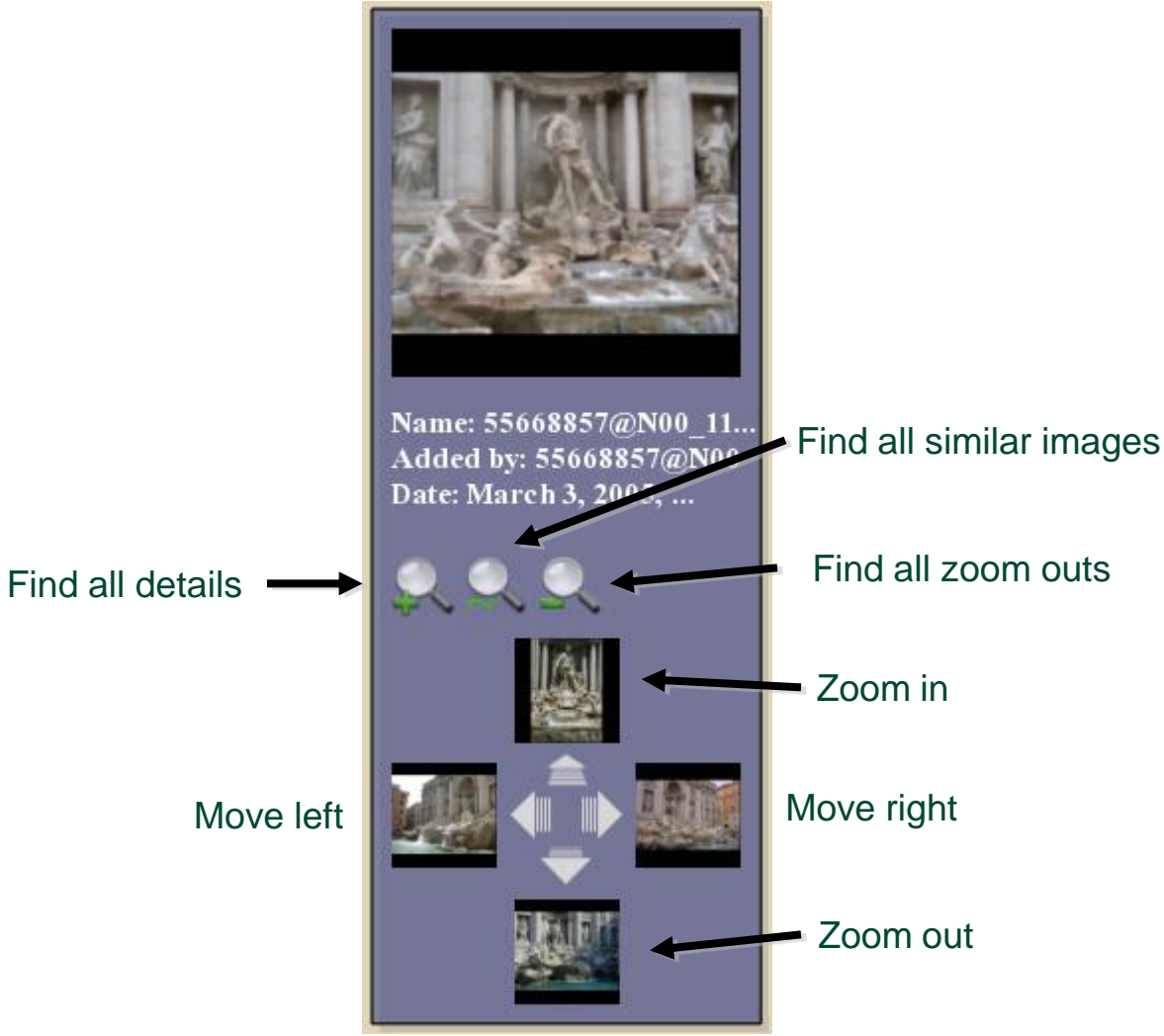
Object-based browsing



- Visibility
- Resolution
- Head-on view or oblique



Relation-based browsing



Relation-based browsing

These relations are inferred based on the relative positions of corresponding feature points between photographs.

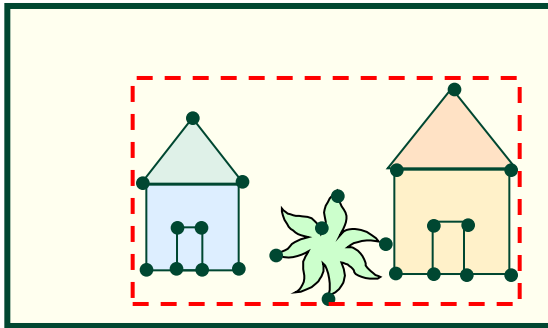


Image A

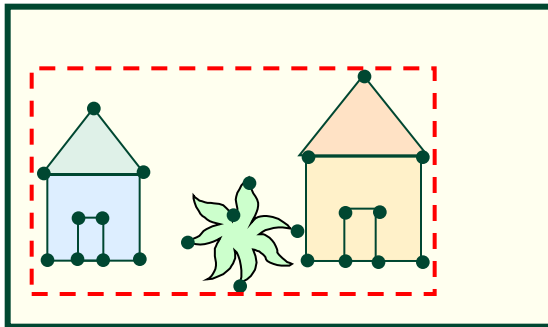


Image B

Relation-based browsing

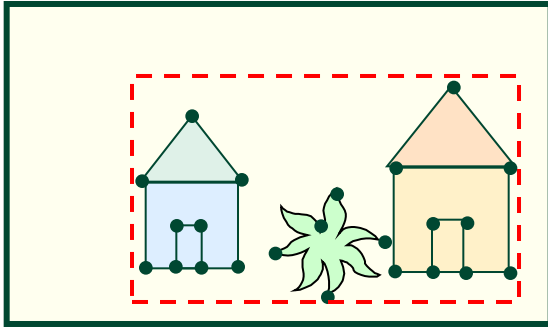


Image A

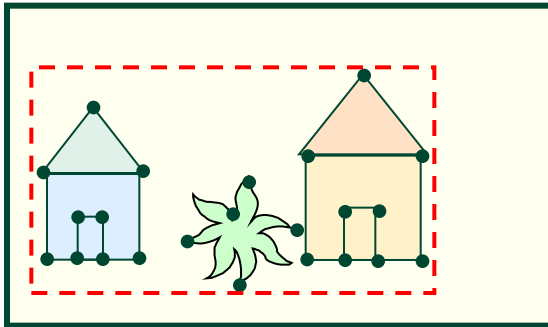
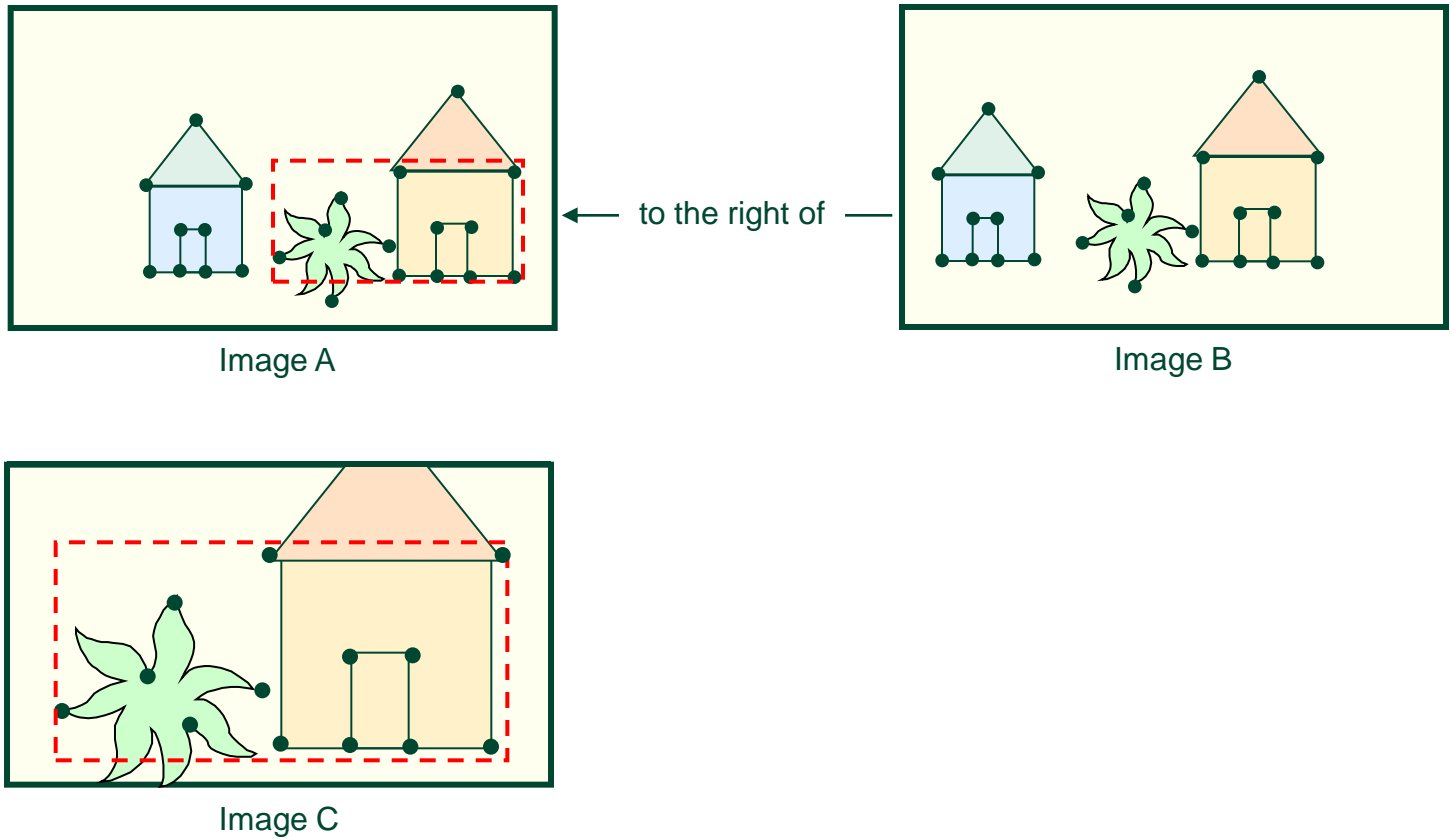
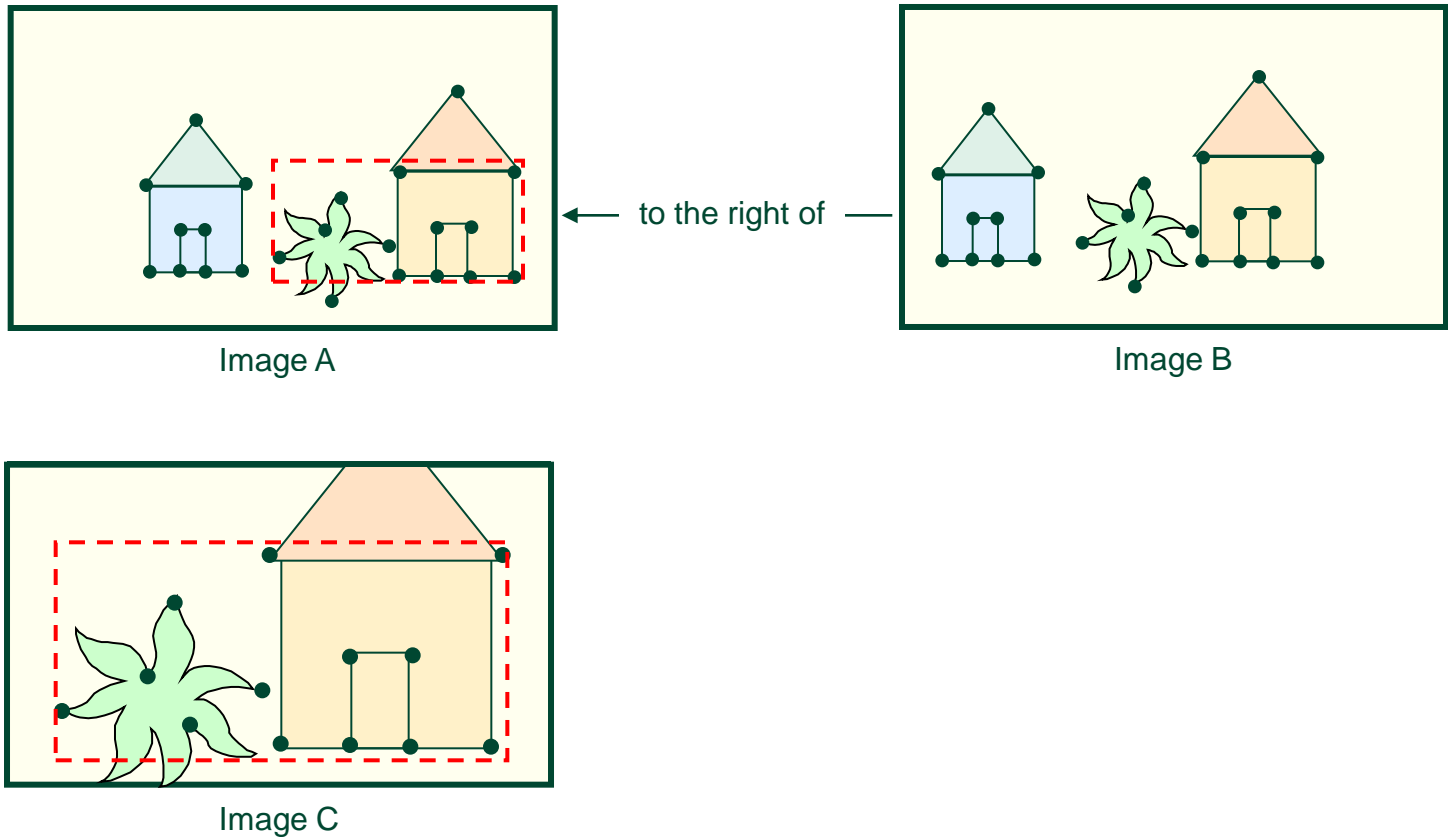


Image B

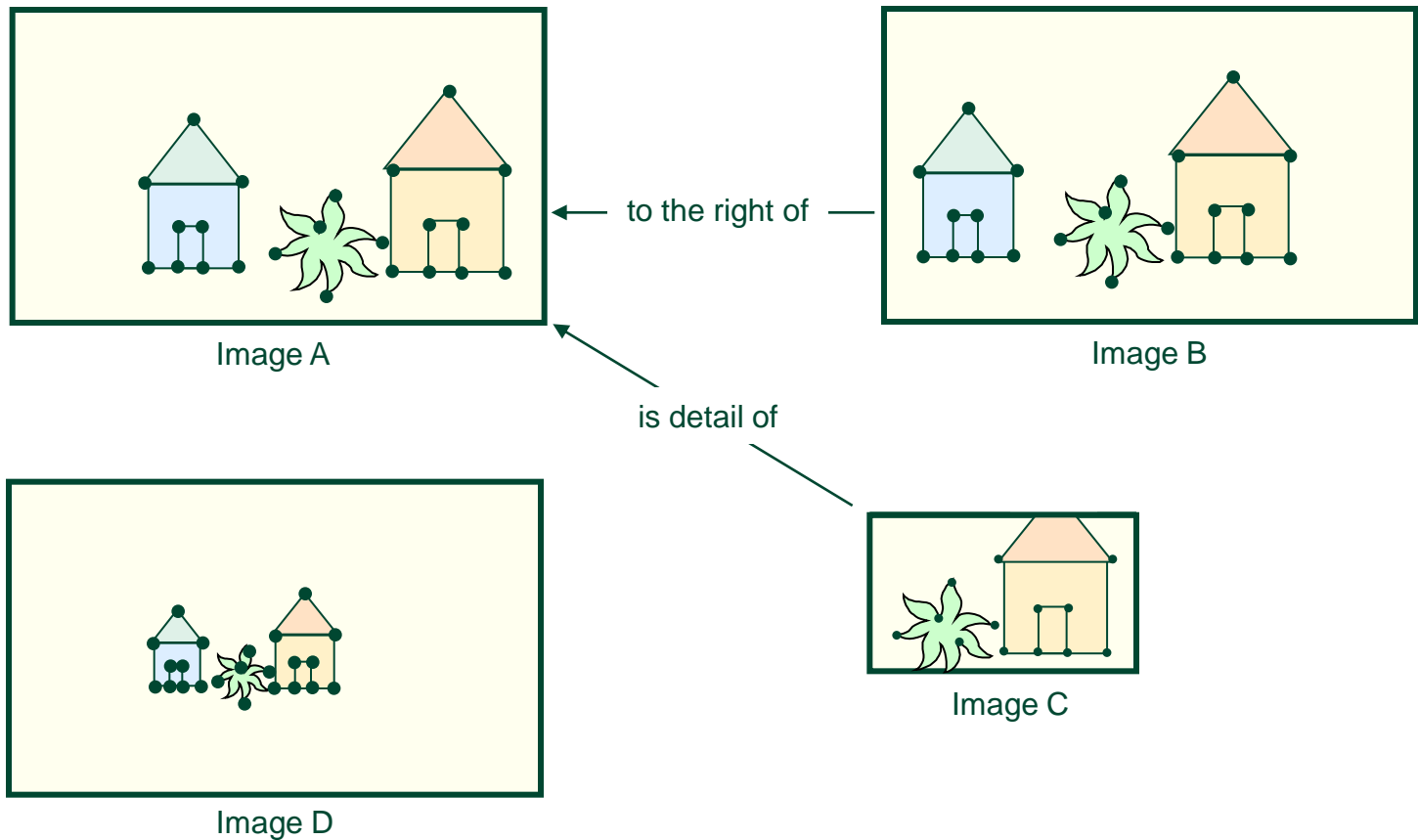
Relation-based browsing



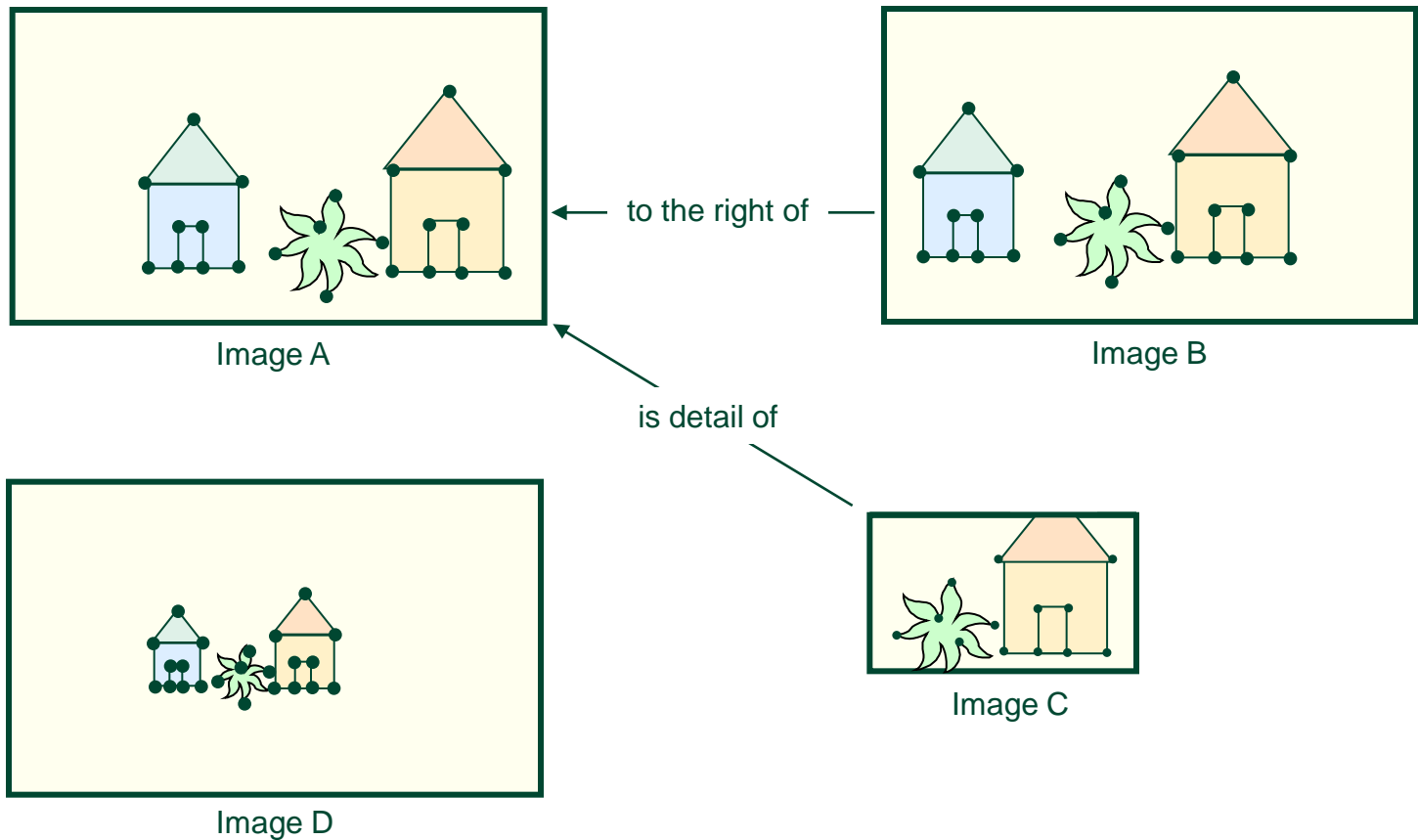
Relation-based browsing



Relation-based browsing



Relation-based browsing



Relation-based browsing

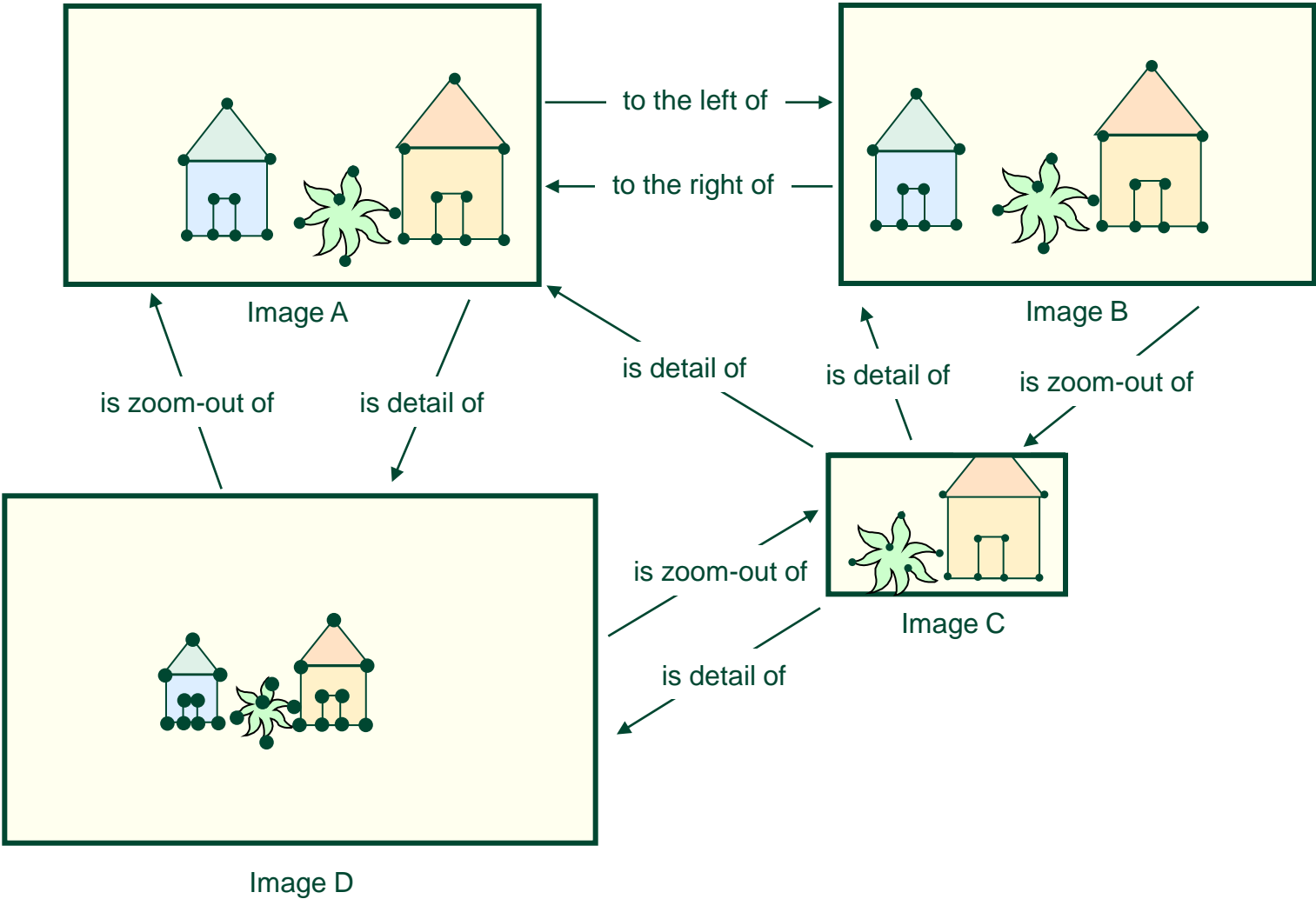
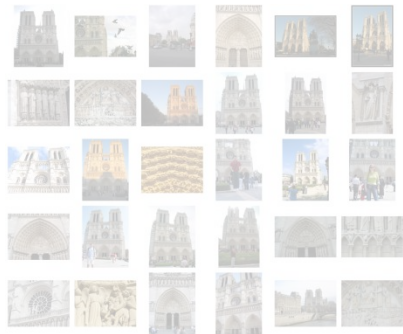
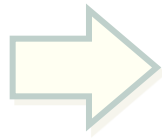


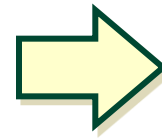
Photo Tourism overview



Input photographs



Scene
reconstruction



- Navigation
- Rendering
- Annotations

Rendering



Rendering(Scene)

3D line segments extracted automatically from the photo collection and these washed-out looking colors



Rendering



Rendering transitions (photographs)

Image-based technique

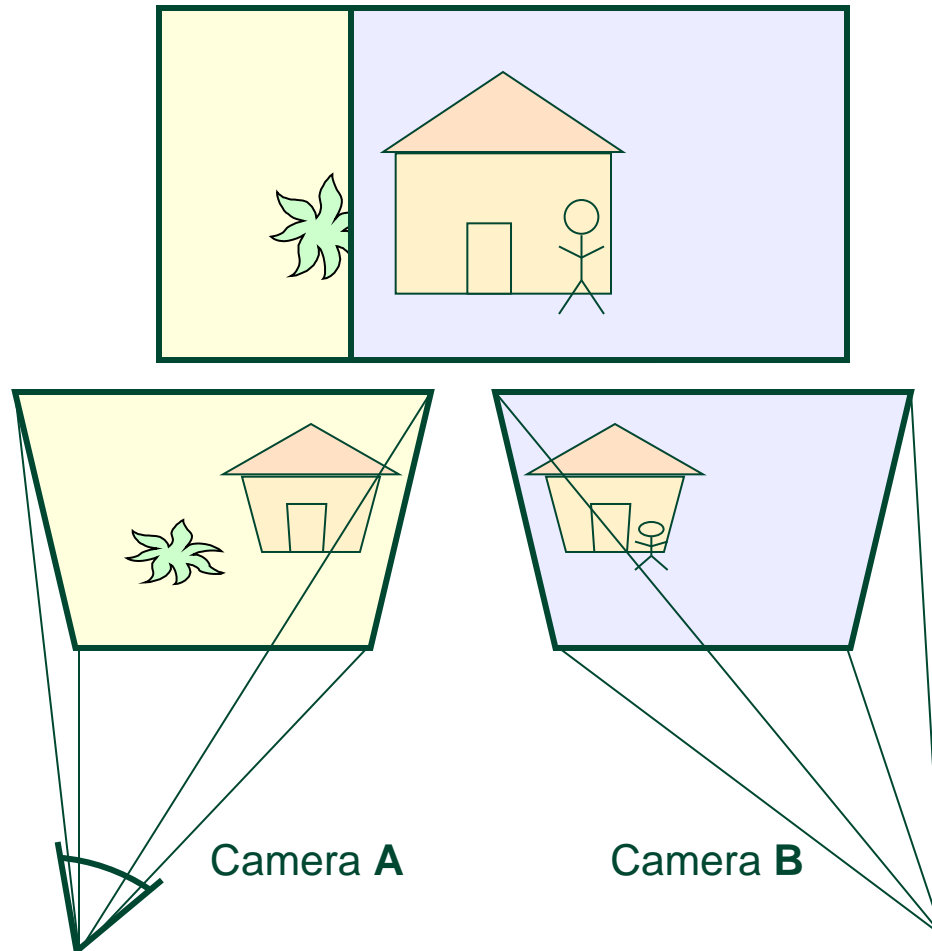
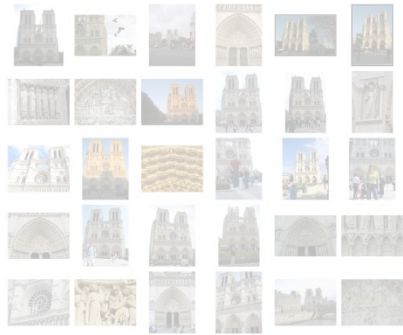
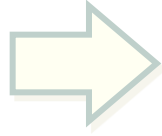


Photo Tourism overview



Input photographs

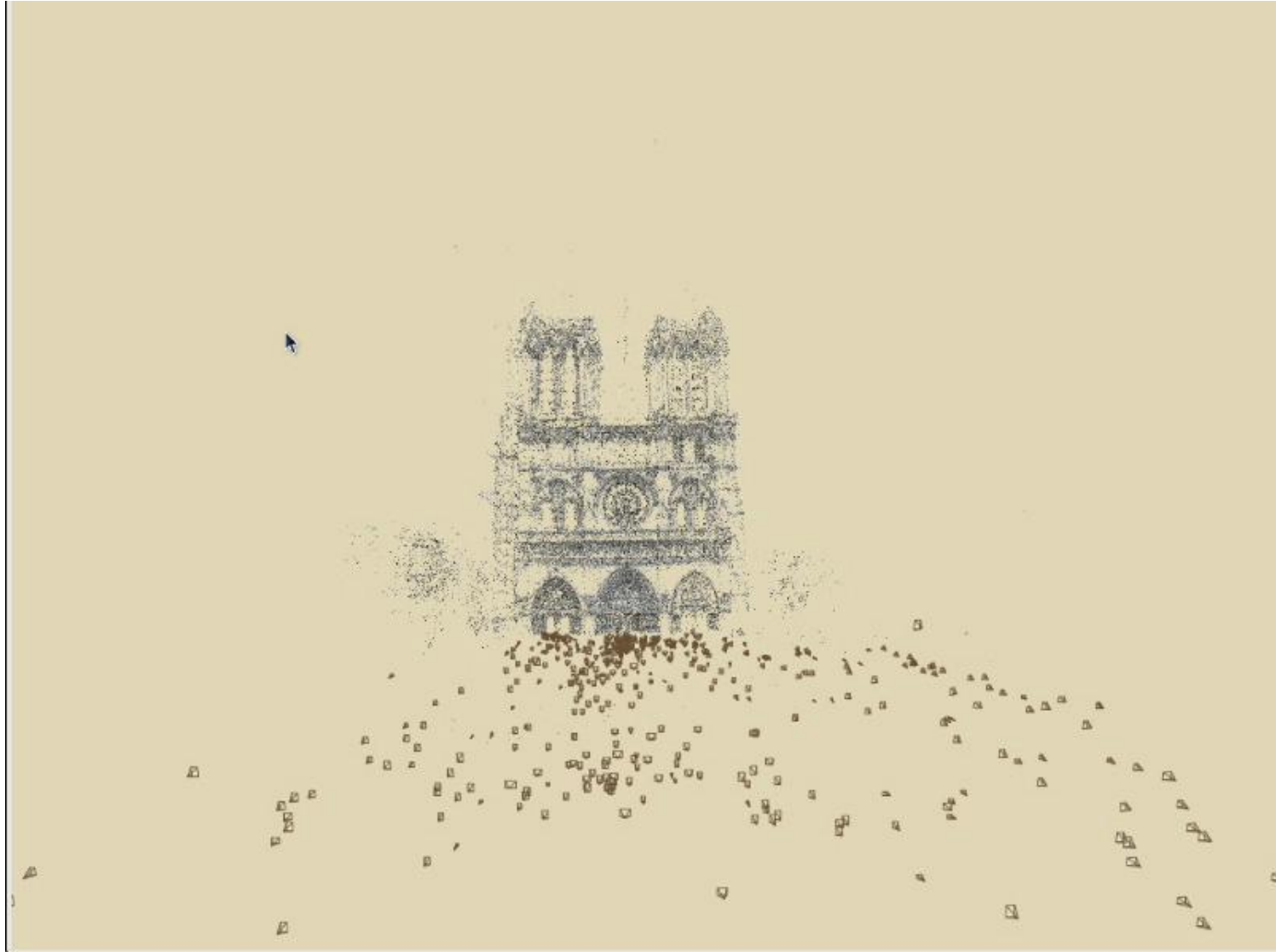


Scene
reconstruction

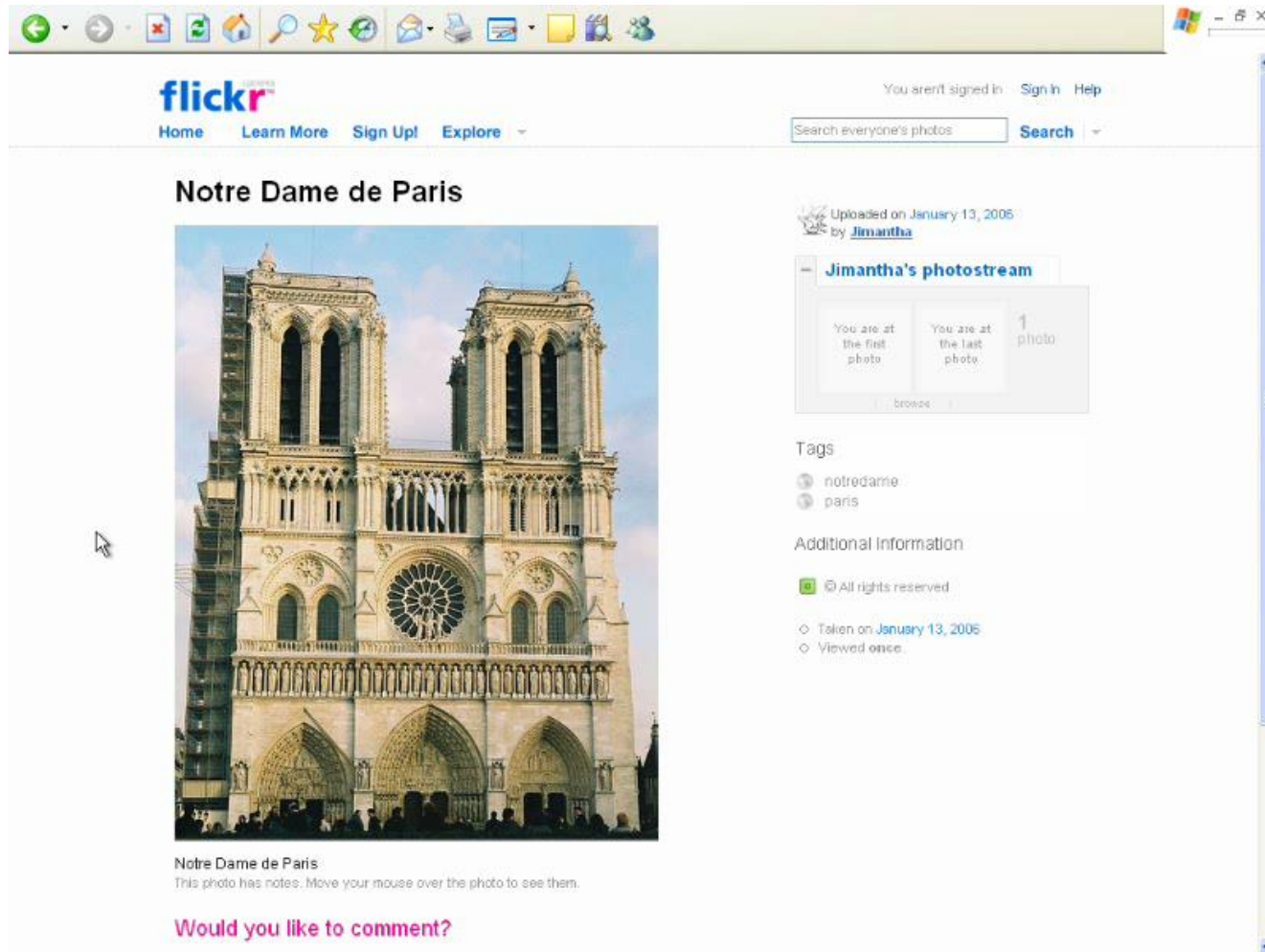


- Navigation
- Rendering
- Annotations

Annotations



Annotations




The screenshot shows a web browser window displaying a Flickr photo page. The browser's address bar is empty, and the taskbar at the bottom shows various application icons. The Flickr page header includes the logo, navigation links (Home, Learn More, Sign Up!, Explore), and a search bar. The main content area features a large photograph of the Notre Dame de Paris cathedral. To the right of the photo is a metadata sidebar with fields for upload date, user name, photostream name, tags, and additional information. Below the photo, there is a caption and a prompt to comment.

flickr
Home Learn More Sign Up! Explore

You aren't signed in Sign In Help

Search everyone's photos Search

Notre Dame de Paris



Uploaded on January 13, 2005
by [Jimantha](#)

Jimantha's photostream

You are at the first photo | You are at the last photo | 1 photo

Tags

- notredame
- paris

Additional Information

- All rights reserved
- Taken on January 13, 2005
- Viewed once

Notre Dame de Paris
This photo has notes. Move your mouse over the photo to see them.

Would you like to comment?

Reproduced with permission of Yahoo! Inc. © 2005 by Yahoo! Inc.
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Contributions

- Automated system for registering photo collections in 3D for interactive exploration
- Structure from motion algorithm demonstrated on hundreds of photos from the Internet
- Photo exploration system combining new image-based rendering and photo navigation techniques

Limitations / Future work

- Not all photos can be reliably matched



- Structure from motion scalability

→ More

ns

- Plane-based



Conclusion

Indexing everyone's photos provides a new way to share and experience our world

To find out more:

- <http://phototour.cs.washington.edu>
- <http://research.microsoft.com/IVM/PhotoTourism>
- <http://labs.live.com/photosynth>
- Exhibition booth #2619



Saint Basil's Cathedral



Trafalgar Square



Rockefeller Center



Mount Rushmore

FaceTracer:

**A Search Engine for Large
Collections of Images with
Faces**

Neeraj Kumar,
Peter Belhumeur, Shree Nayar

Columbia University

How Can We Describe This Face?

Woman

Young

Asian



Brunette

Smiling

...

How Can We Describe The Image?

Indoors

Flash

In Focus



Frontal

Alone

...

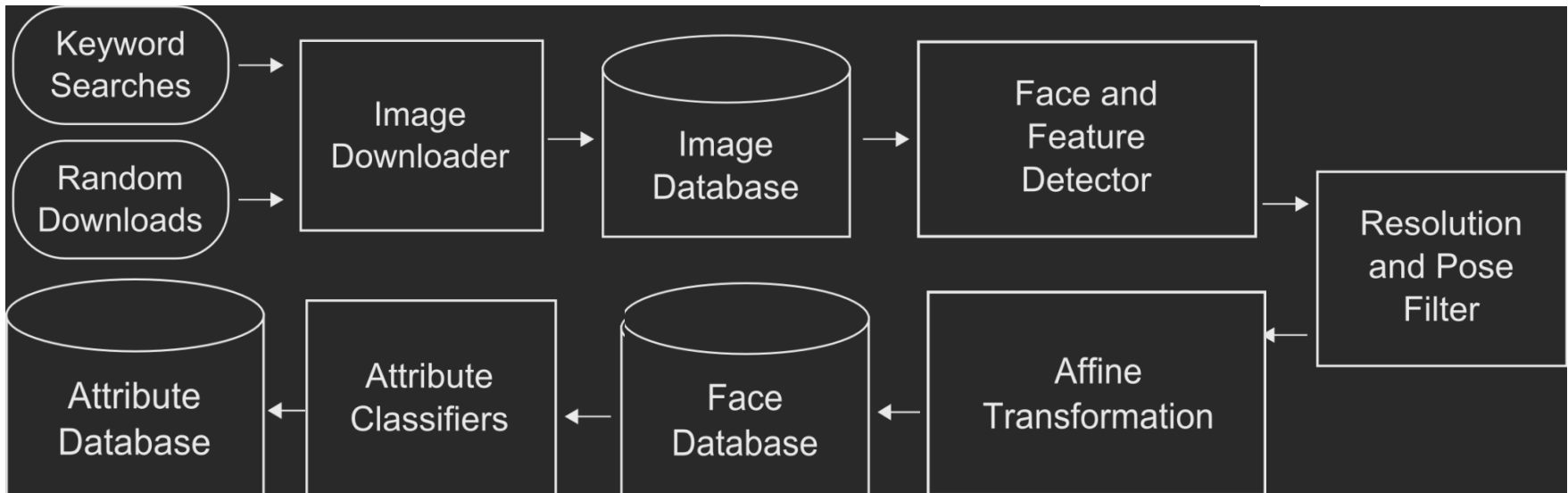
We Need a Search Engine Based on Facial and Image Appearance

Some Numbers

- Billions of Images
- Hundreds of Attributes
- Thousands of Manual Labels

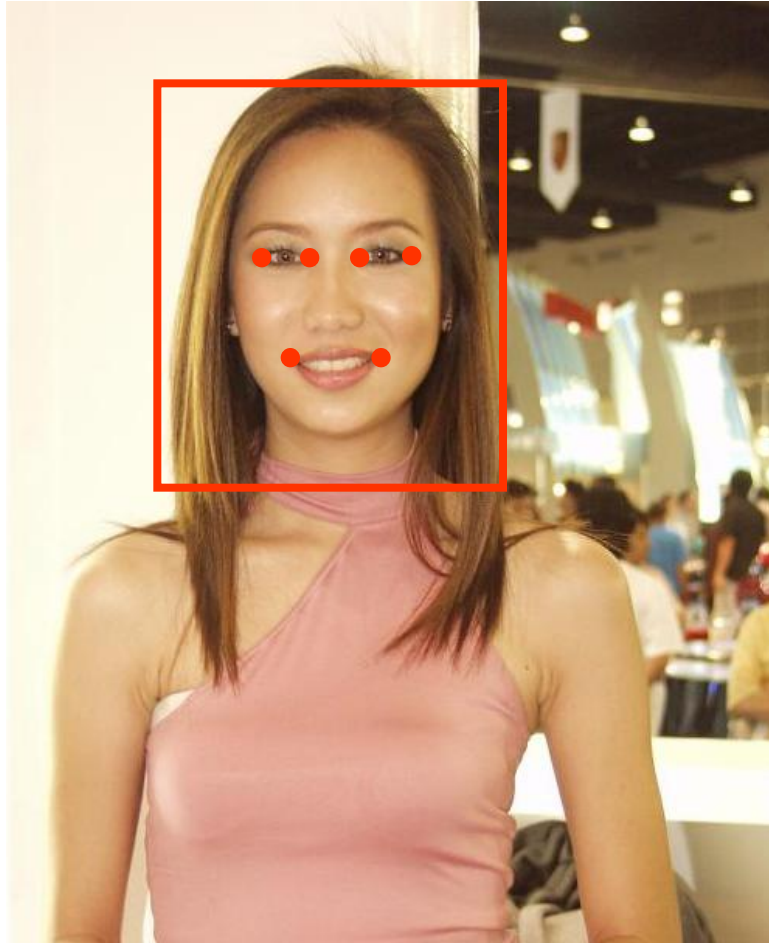
We need to do this automatically

Overview of Database Creation

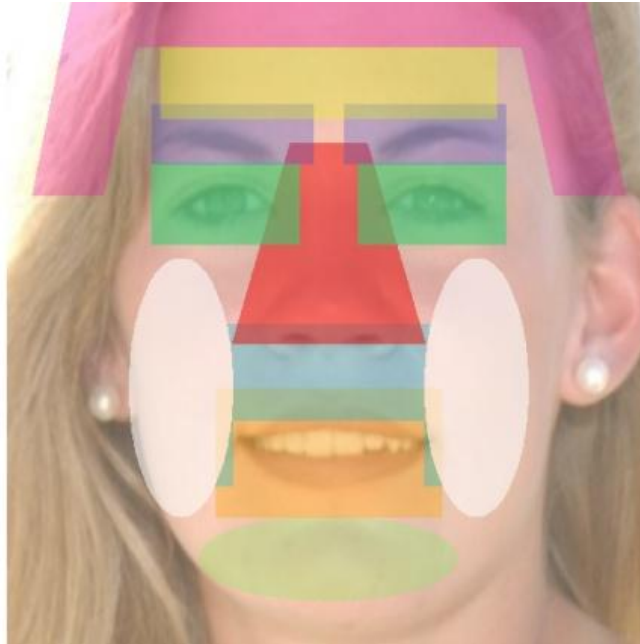
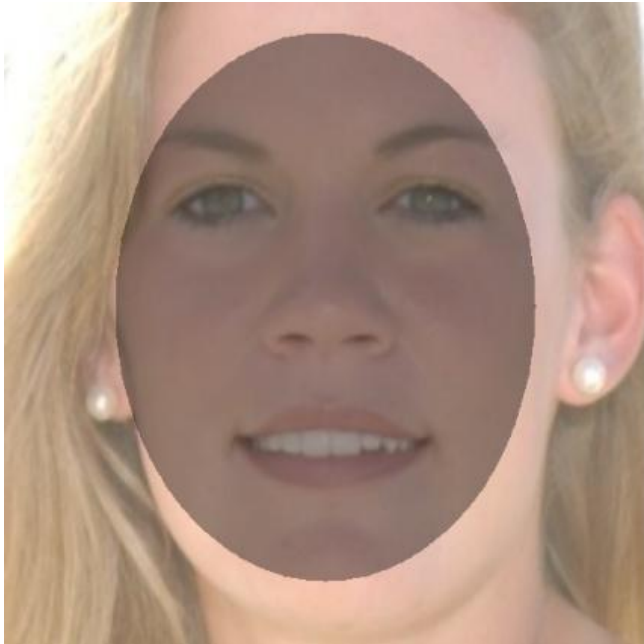


- OKAO face detector
 - Pose angles
 - 6 Facial keypoints location
- Alignment by linear least squares on detected facial points and corresponding points on a template face.

Detect and Align



1. Face Regions



- Whole Face (W)
- Hair (H)
- Forehead (F)
- Eyebrows (B)
- Eyes (E)
- Nose (N)
- Cheeks (K)
- Upper Lip (U)
- Mouth (M)
- Chin (C)

Feature Types

2. Pixel Value Type	3. Normalizations	Aggregation
RGB (r)	None (n)	None (n)
HSV (h)	Mean-Norm (m)	Histogram (h)
Image Intensity (i)	Energy-Norm (e)	Statistics (s)
Edge Magnitude (m)		
Edge Orientation (o)		

Feature Types

Pixel Value Type	Normalizations	Aggregation
RGB (r)	None (n)	None (n)
HSV (h)	Mean-Norm (m)	Histogram (h)
Image Intensity (i)	Energy-Norm (e)	Statistics (s)
Edge Magnitude (m)		
Edge Orientation (o)		

“Region:pixel type.normalization.aggregation.”

RGB, Mean Norm., No Aggreg. (r.m.n)

Feature Types

Pixel Value Type	Normalizations	Aggregation
RGB (r)	None (n)	None (n)
HSV (h)	Mean-Norm (m)	Histogram (h)
Image Intensity (i)	Energy-Norm (e)	Statistics (s)
Edge Magnitude (m)		
Edge Orientation (o)		

“Region:pixel.type.normalization.aggregation.”

Edge Orientations, No Norm, Histogram (o.n.h)

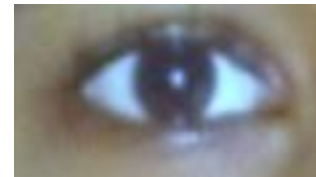
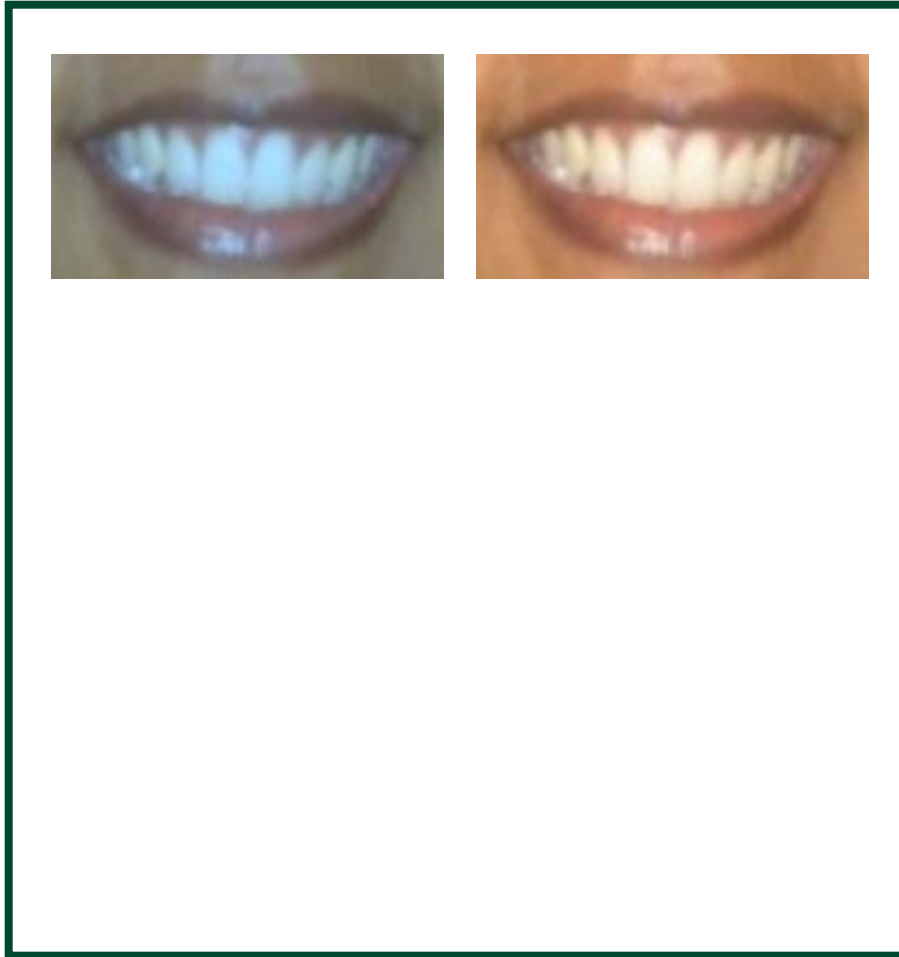
Train Classifiers



Mouth
Raw RGB

Pool of Classifiers- one per region/feature type

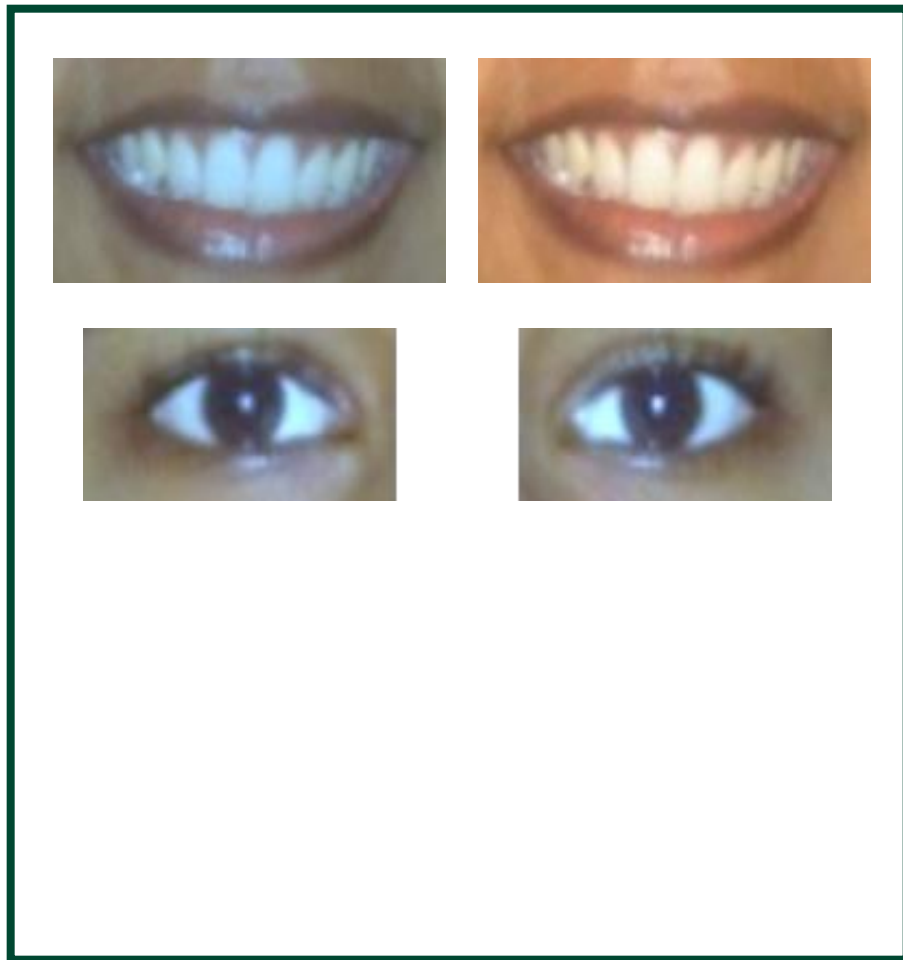
Train Classifiers



Eyes
Mean-Normalized RGB

Pool of Classifiers- one per region/feature type

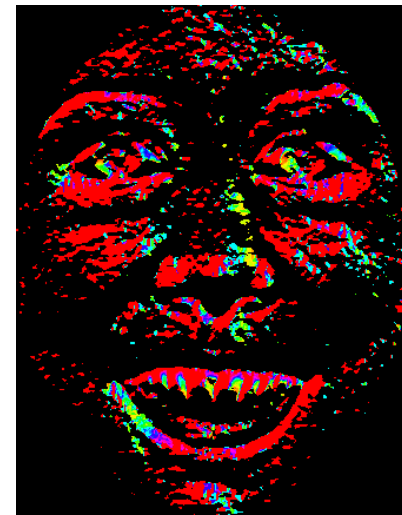
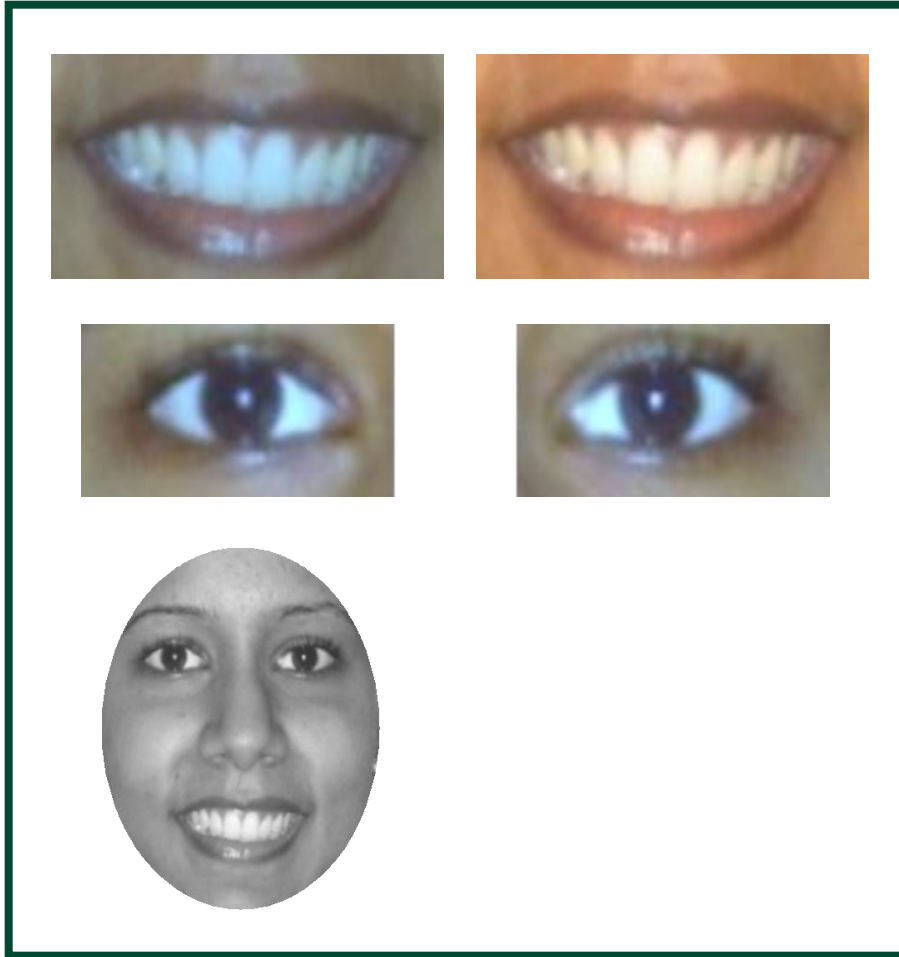
Train Classifiers



Whole Face
Raw Intensity

Pool of Classifiers- one per region/feature type

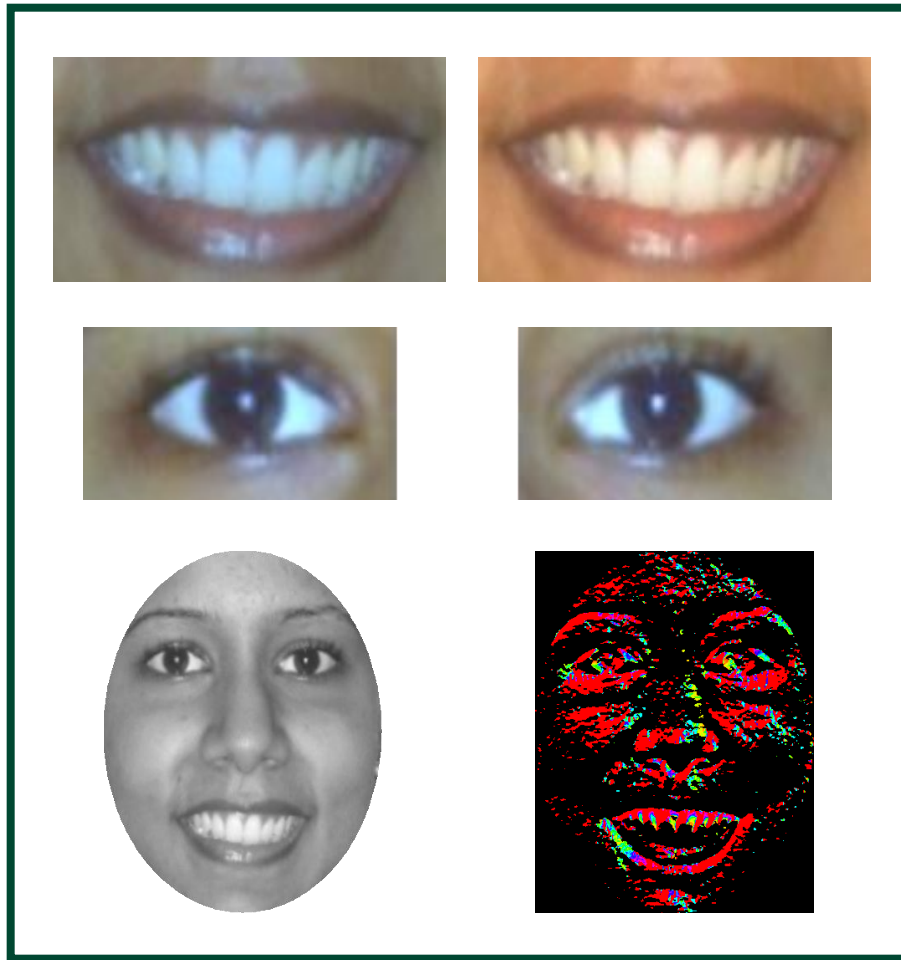
Train Classifiers



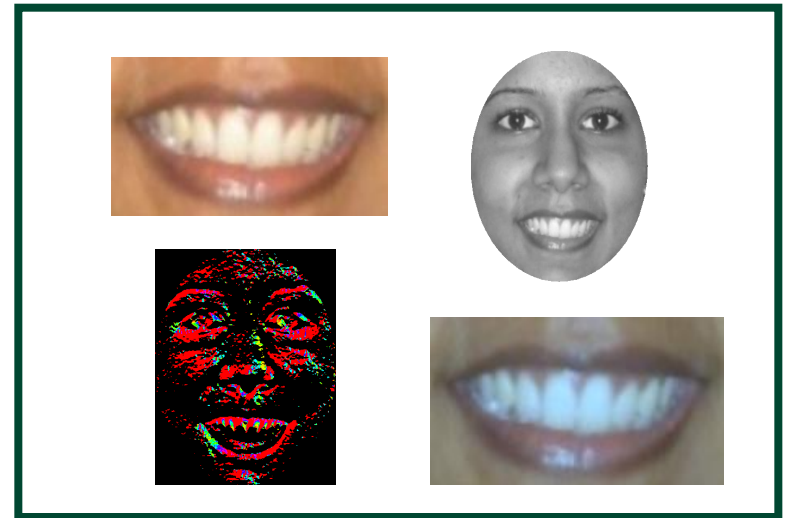
Whole Face
Gradient Directions

Pool of Classifiers- one per region/feature type

Select Classifiers

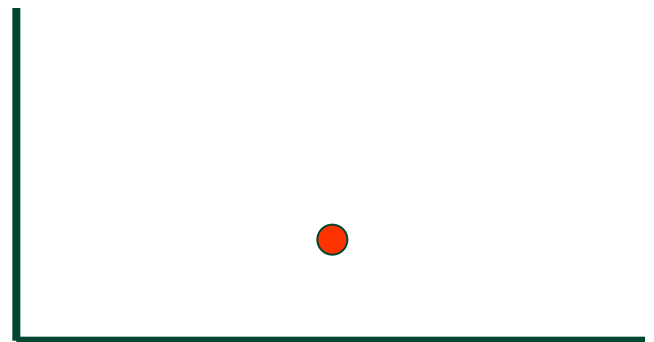


Pool of Classifiers



Selected Classifiers

Error Rate



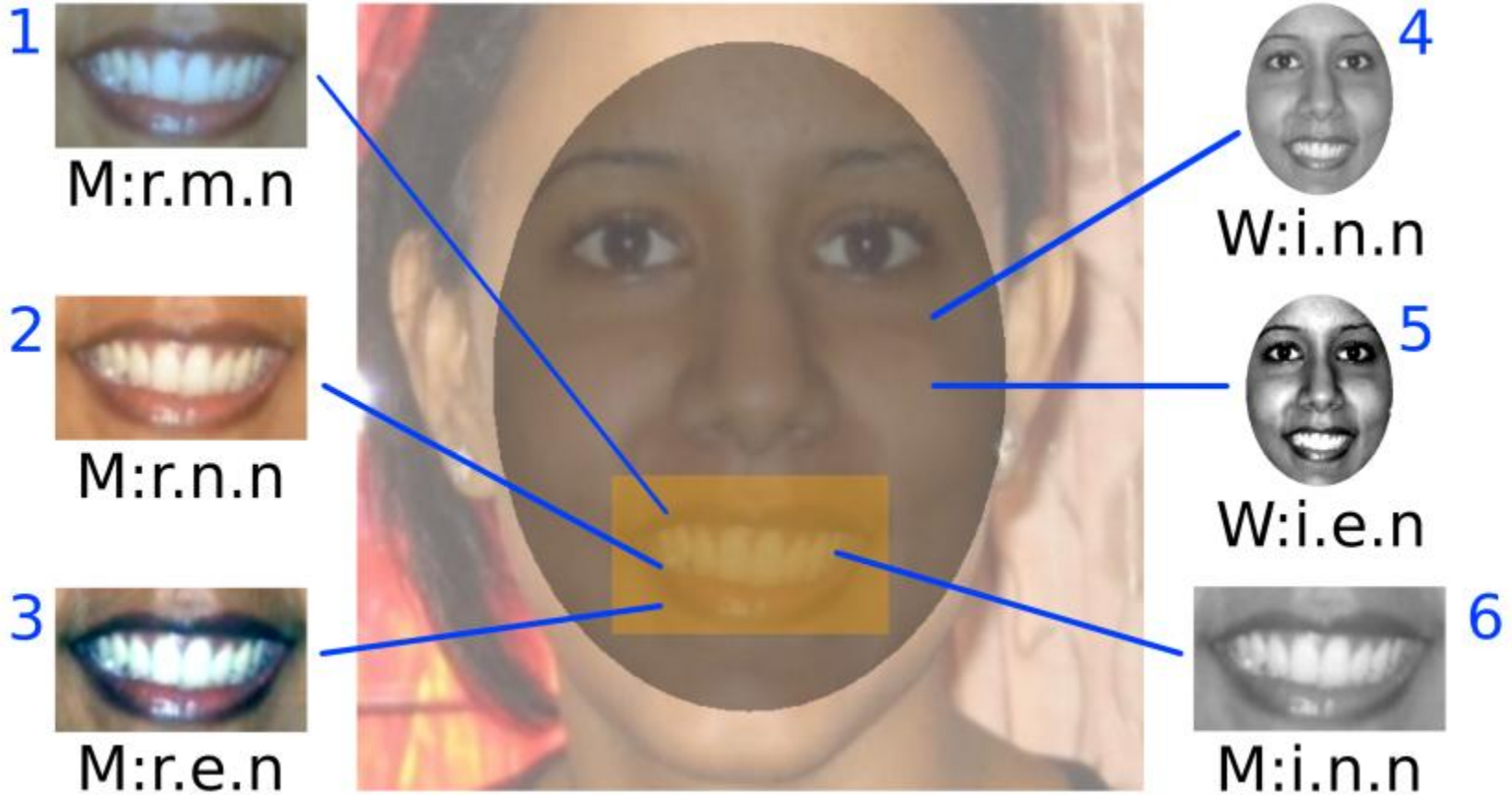
Iteration

Feature Selection: Smiling

1. Mouth: RGB, Mean Norm., No Aggreg. (M:r.m.n)
2. Mouth: RGB, No Norm., No Aggreg. (M:r.n.n)
3. Mouth: RGB, Energy Norm., No Aggreg. (M:r.e.n)
4. Whole Face: Intensity, No Norm., No Aggreg. (W:i.n.n)
5. ...



Selected Features



Smiling

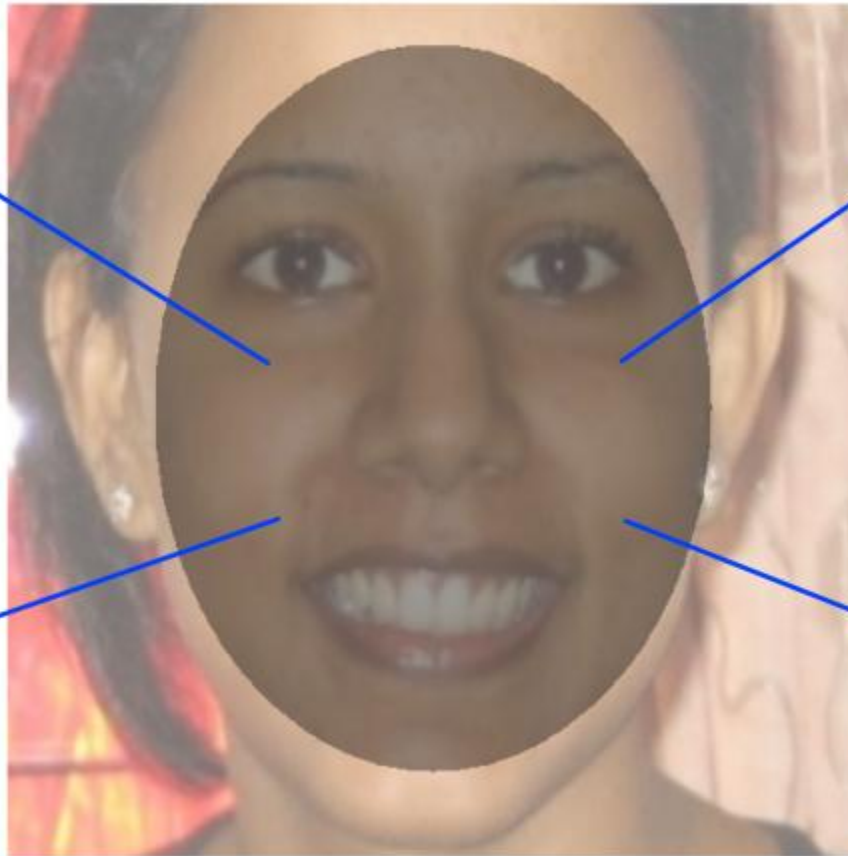
Selected Features



W:i.m.n



W:o.n.n



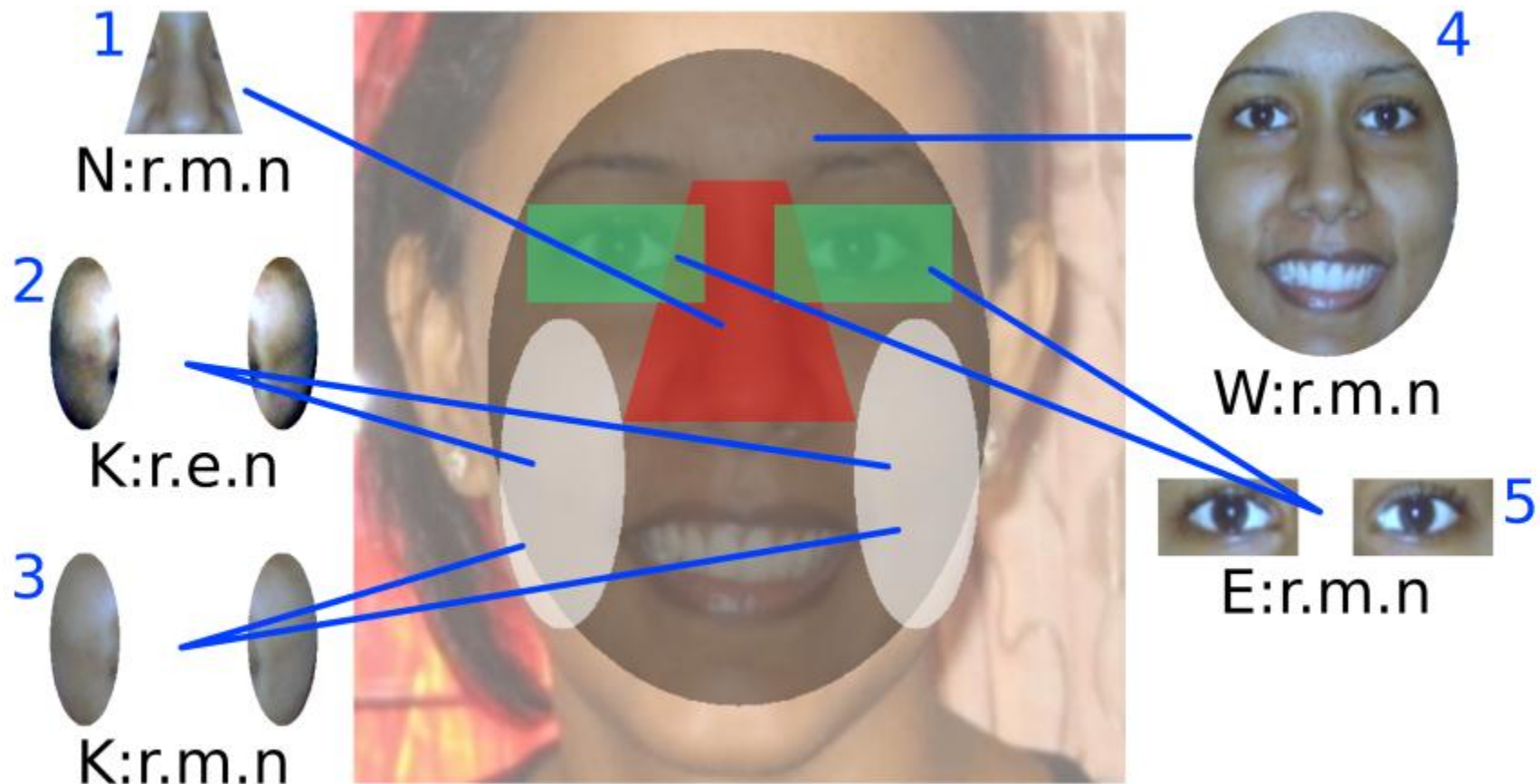
W:i.n.n



W:i.e.n

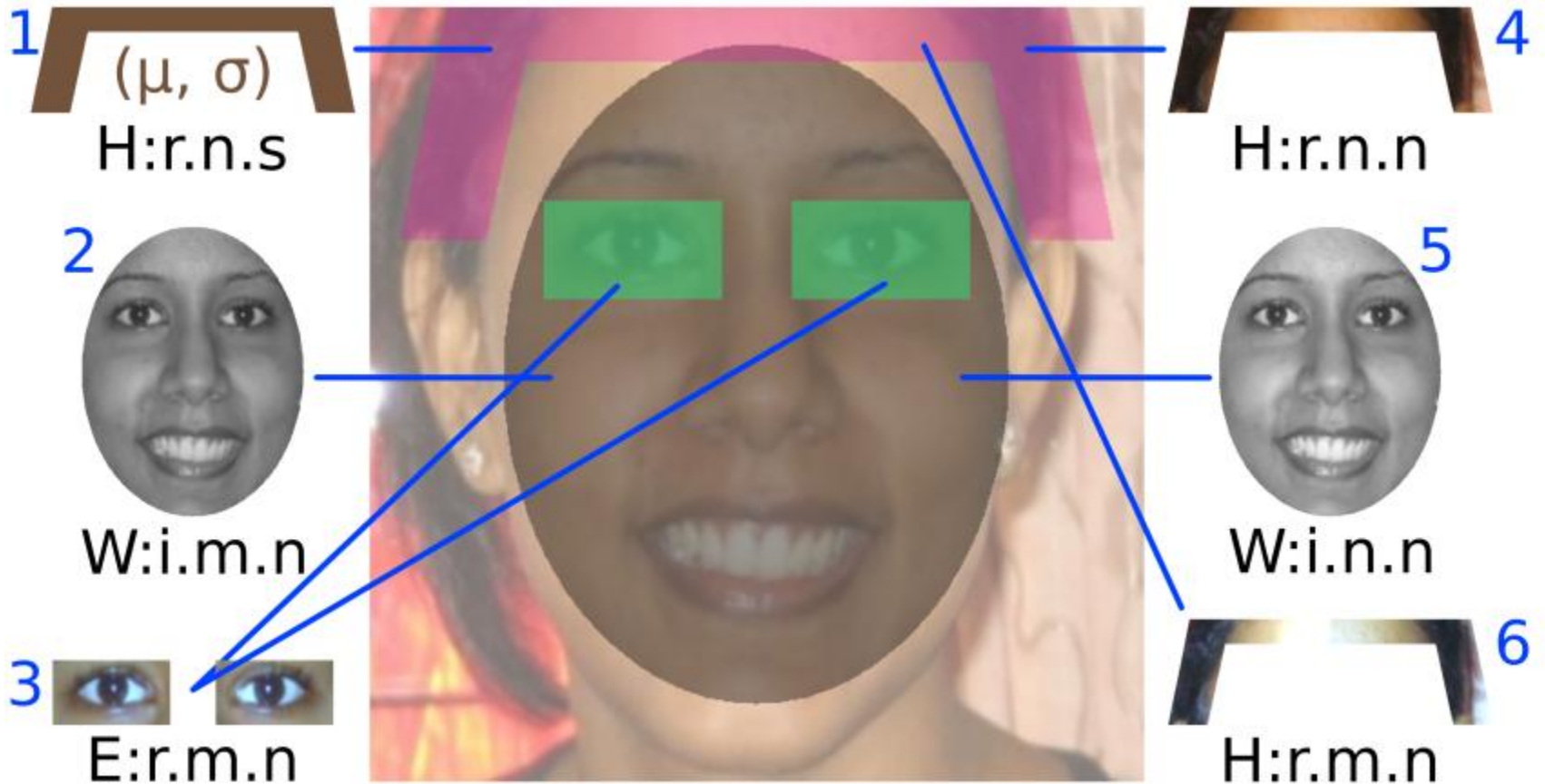
Gender

Selected Features



Indoor/Outdoor

Selected Features



Hair Color

Classification Accuracy

Attribute	Error Rate
Gender	8.62%
Age	16.65%
Race	6.49%
Hair Color	5.54%
Eye Wear	5.14%

Attribute	Error Rate
Mustache	4.61%
Smiling	4.60%
Blurry	3.41%
Lighting	1.61%
Environment	12.15%

Comparison to State-of-the-Art

Method	Gender Error Rate	Smiling Error Rate
Proposed	8.62%	4.60%
Baluja & Rowley, IJCV 2007	13.13%	7.41%
Shakhnarovich et al., ICAFG 2002	12.88%	6.40%
Moghaddam & Yang, TPAMI 2002	9.52%	13.54%

Results

“Adults Outside”

phizard^{alpha}

Parsed query as: age is not child, age is not baby, environ
Found 1000 results in 1.113 secs. Displaying results

Aligned Faces Images

Web Images Maps News Shopping Gmail more

Google [Advanced Image Search Preferences](#)
Moderate SafeSearch is on [New! Google Image Labeler](#)

Images Showing: All image sizes Results 1 - 20 of about 1,860,000 for **adults outside**. (0.12 seconds)

... French-speaking **adults outside** ... children and **adults outside** ...
517 x 332 - 13k - gif www.statcan.ca [[More from www.statcan.ca](#)]

China Update!
448 x 336 - 56k - jpg www.missiongrounds.com

... waits with **adults outside** her ...
610 x 400 - 55k - jpg www.daylife.com [[More from cache.daylife.com](#)]

... waits with **adults outside** her ...
610 x 357 - 61k - jpg www.daylife.com

... for **Adults - Outside** patio
2532 x 1496 - 502k - jpg www.co.greene.oh.us [[More from www.co.greene.oh.us](#)]

Today Center for **Adults - Outside**
1113 x 835 - 262k - jpg www.co.greene.oh.us

Four **Adults Outside** a Building photo
400 x 293 - 36k - jpg www.inmagine.com [[More from images.inmagine.com](#)]

Seven young **adults outside** Poston II ...
650 x 373 - 62k content.cdlib.org

... cuyabana **adults outside** of soil, ...
400 x 395 - 3k - gif www.scielo.br

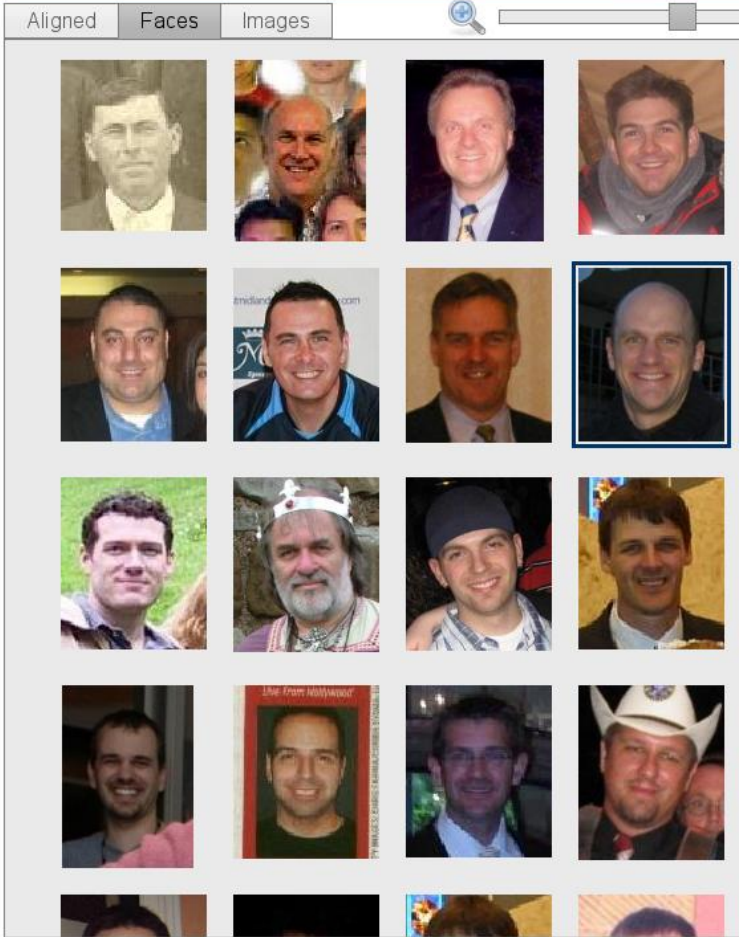
Paradise for **adults**. **Outside** of ...
500 x 300 - 25k - jpg www.markwarner.co.uk

French speaking **adults outside**
472 x 332 - 6k - gif www.statcan.ca

“Middle-Aged White Men”

phizard Search Faces
 face search Example searches: women with no glasses, non adults Show Attributes

Parsed query as: age is middle aged, race is white, race is not asian, gender is m
 Found 1000 results in 1.053 secs. Displaying results



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Google Search Images Search the Web Advanced Image Search Preferences
 Moderate SafeSearch is on New! Google Image Labeler

Images Showing: All image sizes Results 1 - 20 of about 169,000 for middle-aged white men. (0.04 seconds)

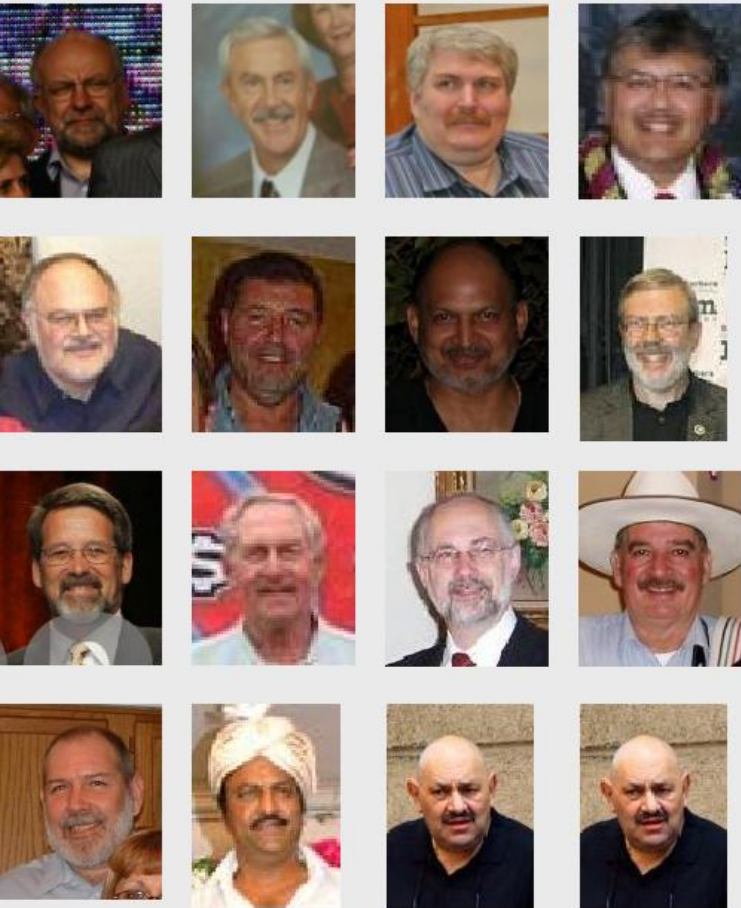


“Old Men With Mustaches”

phizard^{alpha}
face search Example searches: sunglasses outside, asian men with glasses

Parsed query as: age is middle aged, age is senior, age is not child, age is not baby, and true.
Found 1000 results in 1.415 secs. Displaying results

Aligned Faces Images




Live Search

Images 1-5 of 6 · [Web](#) · [Video](#) · [News](#) · [Maps](#) · [More](#) ▾

SafeSearch Moderate ([Change](#))

5.jpg



dimensions: 448x336
file size: 29kB
www.supercw.com/archive/4aug05.html
[add to scratchpad](#)
[feedback on this image](#)

“People Wearing Sunglasses Outside”

phizard
face search

people wearing sunglasses outside

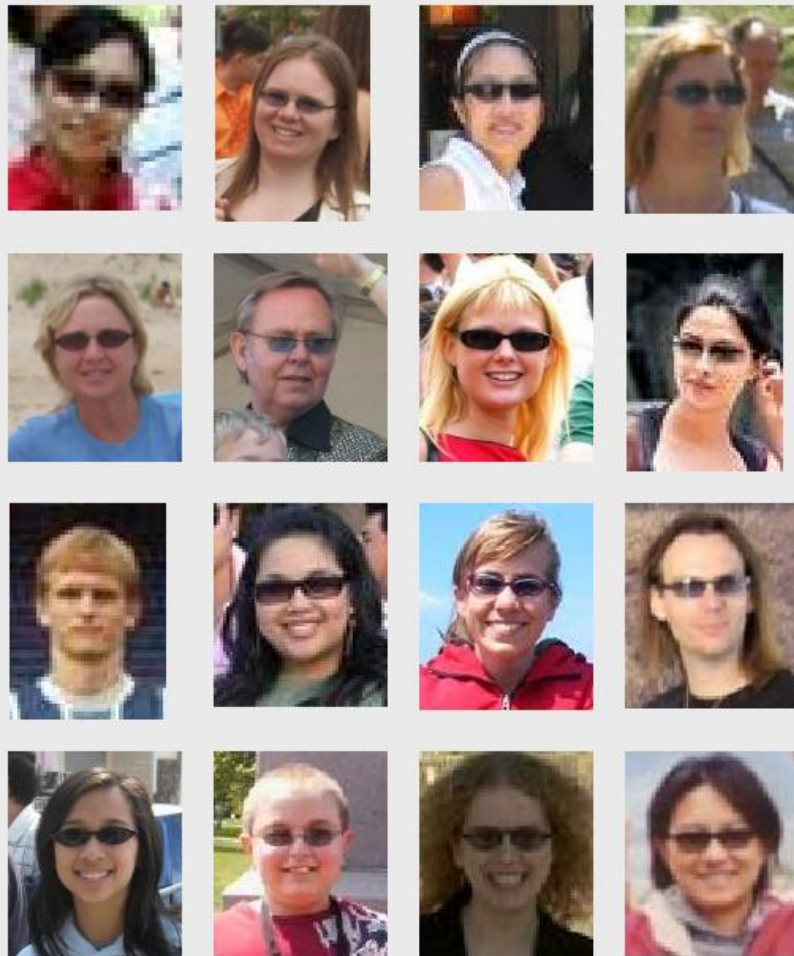
Search Faces

Example searches: non adults, white children

Show Attributes

Parsed query as: eye wear is sunglasses, eye wear is not none, e
Found 1000 results in 0.153 secs. Displaying results

Aligned Faces Images



Live Search | MSN | Windows Live | Hotmail

Un



Live Search

people wearing sunglasses outside



Images 1-12 of 27 · [Web](#), [Video](#), [News](#), [Maps](#), [More](#) ▾

SafeSearch Moderate ([Change](#))



fa_osshades.jpg



dimensions: 405x336
file size: 17kB
www.diversetraveller.com/DT_ArticlesList.as
[add to scratchpad](#)
[feedback on this image](#)





“Kids Indoors Not Smiling”

phizard

face search Example searches: asian men with glasses, men with dark hair

Parsed query as: age is child, age is not middle aged, environment is indoor, expression is not smiling.
Found 1000 results in 0.521 secs. Displaying results 1 to 48.

Aligned Faces Images



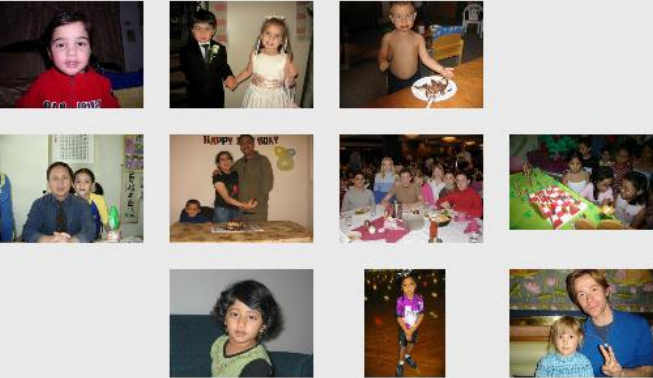
[Open Original Image](#)
[Open Source Page](#)

phizard

face search Example searches: asian men with glasses, men with dark hair

Parsed query as: age is child, age is not middle aged, environment is ind
Found 1000 results in 0.521 secs. Displaying result

Aligned Faces Images



flickr®

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You aren't signed in [Sign In](#) [Help](#)

▾

Search

Photos

[Groups](#)

[People](#)

[Advanced Search](#)
[Search by Camera](#)

Full text Tags only

! We couldn't find any results matching "kids indoors" and not smiling.

Would you like to try a search for [smile](#), [happy](#), [girl](#), [portrait](#) or [woman](#) instead?

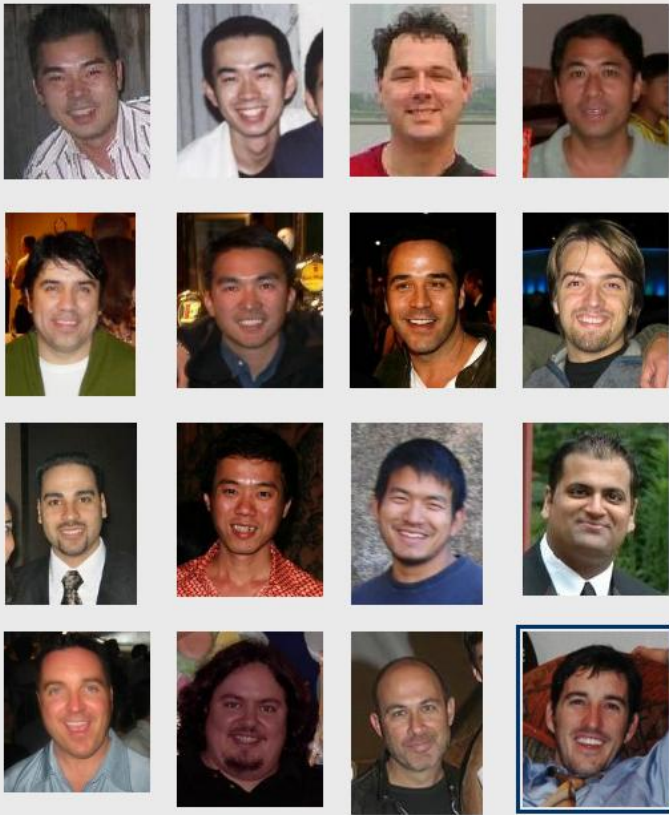
“Men With Dark Hair”

phizard^{alpha}

face search Example searches: white children, old women outside

Parsed query as: gender is male, age is not child, age is not baby
Found 1000 results in 1.046 secs. Displaying results

Aligned Faces Images















Yahoo! My Yahoo! Mail Welcome, Guest [Sign In] Help

YAHOO! SEARCH [Advanced Search Preferences](#)

SafeSearch is on (turn off)

Image Results 1 - 20 of about 589 for men with dark hair - 0.08 sec.

Show: All | Wallpaper - Large - Medium - Small | Color - Black & White



 <p>Just for Men sh...ck.bmp 120 x 180 63.3kB www.rowlandpharmacy.co.uk</p>	 <p>alone in the dark By FatoOoma Qata... on Flickr www.flickr.com</p>	 <p>handsomest hair model 11 yianni By letslookupand... on Flickr www.flickr.com</p>	 <p>handsomest hair model 13 doug By letslookupand... on Flickr www.flickr.com</p>
 <p>handsomest hair model 10 buddy By letslookupand... on Flickr www.flickr.com</p>	 <p>handsomest hair model 9 mike By letslookupand... on Flickr www.flickr.com</p>	 <p>saw him in harajuku By manganite on Flickr www.flickr.com</p>	 <p>men_hair_removal.jpg 270 x 374 24.3kB youre-looking-great.com</p>
 <p>portrait with umbrella By manganite on Flickr www.flickr.com</p>	 <p>patrzy mis parapet By lifedeathpeet on Flickr www.flickr.com</p>	 <p>men By michael_josep... on Flickr www.flickr.com</p>	 <p>parapet By lifedeathpeet on Flickr www.flickr.com</p>

“Smiling Asian Men With Glasses”

phizard^{alpha}
face search Example searches: men with dark hair, flash photos of kids

Parsed query as: expression is smiling, race is asian, gender is male, age is not child, age is not baby, eye wear is eyeglasses.
Found 1000 results in 0.017 secs. Displaying results 1 to 48.

Aligned Faces Images



[Open Original Image](#)
[Open Source Page](#)

[Yahoo!](#) [My Yahoo!](#) [Mail](#) Welcome, **Guest** | [Sign In](#) [Help](#)

[Web](#) | [Images](#) | [Video](#) | [Local](#) | [Shopping](#) | [more >](#)

YAHOO! SEARCH [Advanced Search Preferences](#)

SafeSearch is **on** ([turn off](#))

Image Results

1 - 3 of about 3 for **smiling asian men with glasses** - 0.05 sec.

Show: All | [Wallpaper](#) - [Large](#) - [Medium](#) - [Small](#) | [Color](#) - [Black & White](#)



istockphoto_488...an.jpg
253 x 380 | 23.4kB
www.istockphoto.com

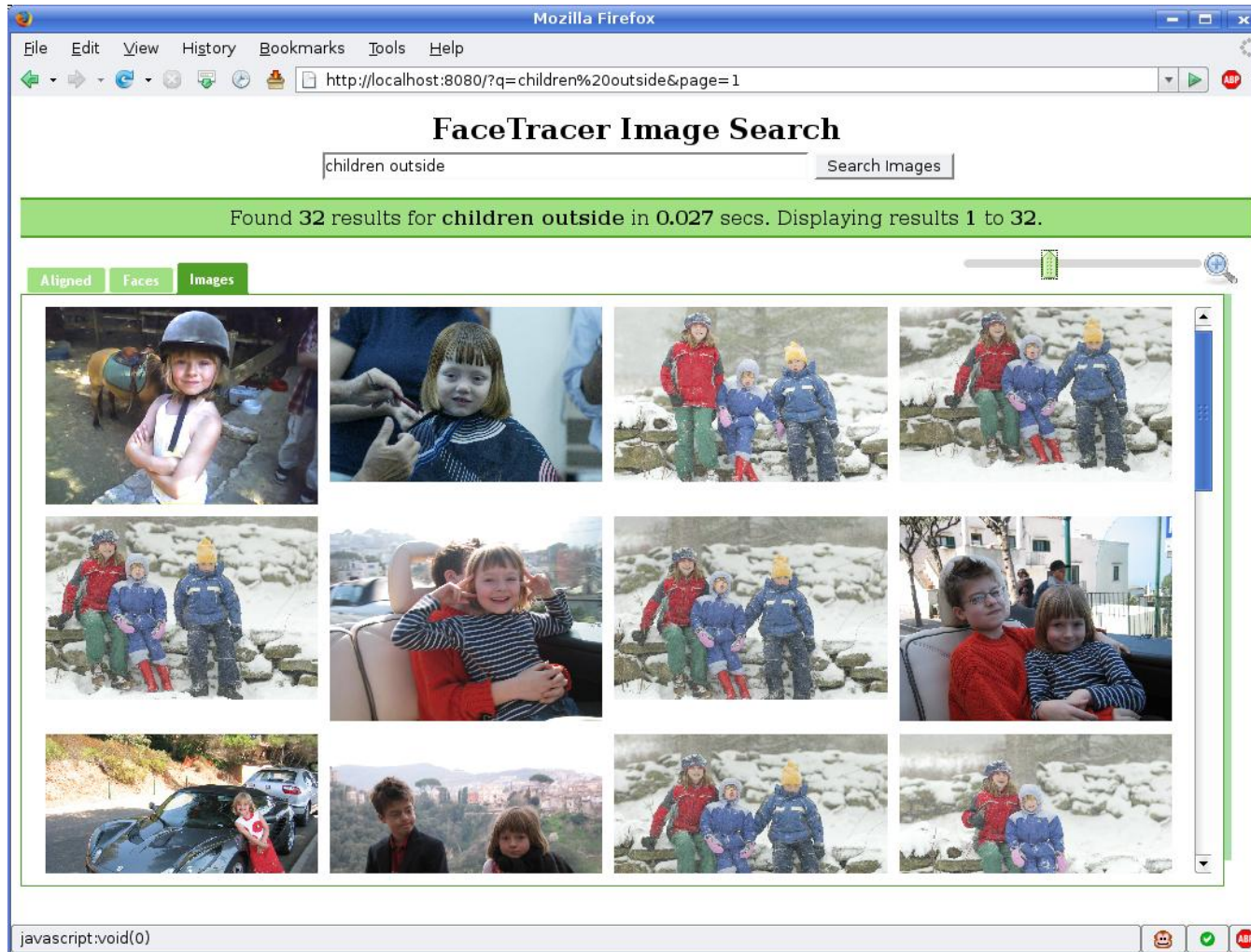


dri029.jpg
400 x 291 | 30.9kB
www.inmagine.com



spo033.jpg
400 x 294 | 37.8kB
www.inmagine.com

Personal FaceTracer Search



“Children outside”



A Computer Vision System for Automatic Plant Species Identification

Neeraj Kumar University of Washington

Peter N. Belhumeur Columbia University

Arijit Biswas University of Maryland

David W. Jacobs University of Maryland

W. John Kress Smithsonian Institution

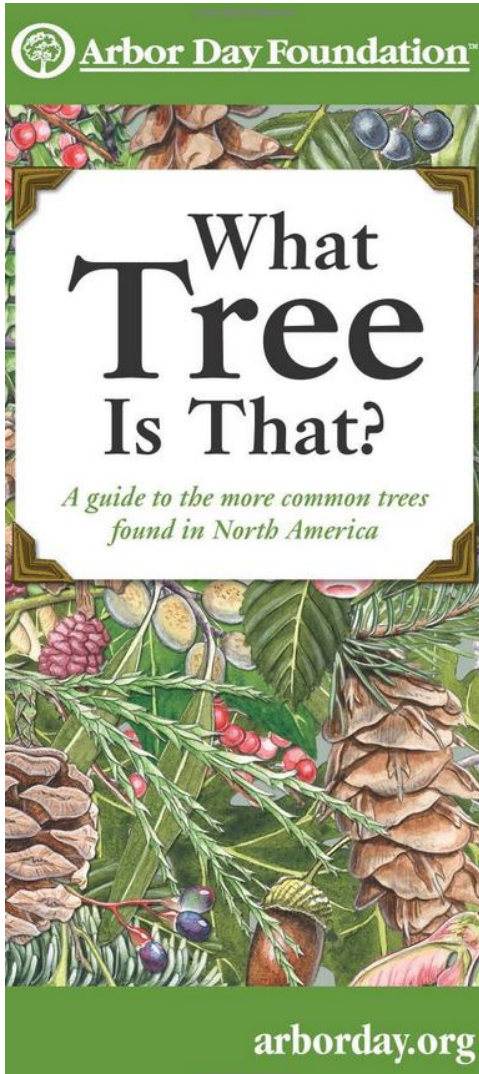
Ida C. Lopez Smithsonian Institution

João V.B. Soares University of Maryland

What Plant Species is this?



Let's Use a Field Guide



7

7 A Are the leaves **SIMPLE** (one **BLADE** attached to a stalk or **PETIOLE**)? **YES** GO TO **7 B**

OR

Are the leaves **COMPOUND** (more than one **BLADE**, attached to a single stalk or **PETIOLE**)? **YES** GO TO **7 C**

OR

Are the uniquely fan-shaped leaves mostly attached, in clusters, to short, **SPUR**-like branches? It is a **ginkgo**. **YES** GO TO **25 B**

7 B Are the **SIMPLE** leaves **OPPOSITE** (2 leaves that are directly across from each other on the same twig)? **YES** GO TO **18 A**

OR

Are the **SIMPLE** leaves **ALTERNATE** (leaves that are staggered, not opposite each other on the twig)? **YES** GO TO **24 B**

7 C Are the **COMPOUND** leaves **OPPOSITE**? **YES** GO TO **20 D**

OR

Are the **COMPOUND** leaves **ALTERNATE**? **YES** GO TO **58 B**

7 D Are the trees **EVERGREEN** with needles arranged in clusters of 2-5? These are pine trees. **YES** GO TO **8 A**

OR

Are the trees **DECIDUOUS**, with needles arranged in clusters of many on short, **SPUR**-like branches? These are larches. **YES** GO TO **12 A**

OR

Are the trees **EVERGREEN** with needles arranged singly? **YES** GO TO **12 B**


OR

Are the trees **DECIDUOUS** with singly attached needles of uneven length flattened along the twig, the cone a 1" (2.5 cm) diameter green or brown wrinkled ball? It is a **baldcypress**. **YES** GO TO **14 D**

9

9 A **EASTERN WHITE PINE**
Pinus strobus
Zones 3-8

The fabled tree eagerly sought by the first wave of loggers in America. The provincial tree of Ontario.




9 B **DITCH PINE**
Pinus rigida
Zones 4-7

The fire resilient conifer of the East, even producing new branches and needles after fire kills the green foliage.



9 C **LONGLEAF PINE**
Pinus palustris
Zones 7-10

A tall, stately pine of the South long sought by loggers.



9 D **LOBLOLLY PINE**
Pinus taeda
Zones 6-9

Our most important and widely cultivated timber species in the southern United States.





Like a normal field guide...





Like a normal field guide...

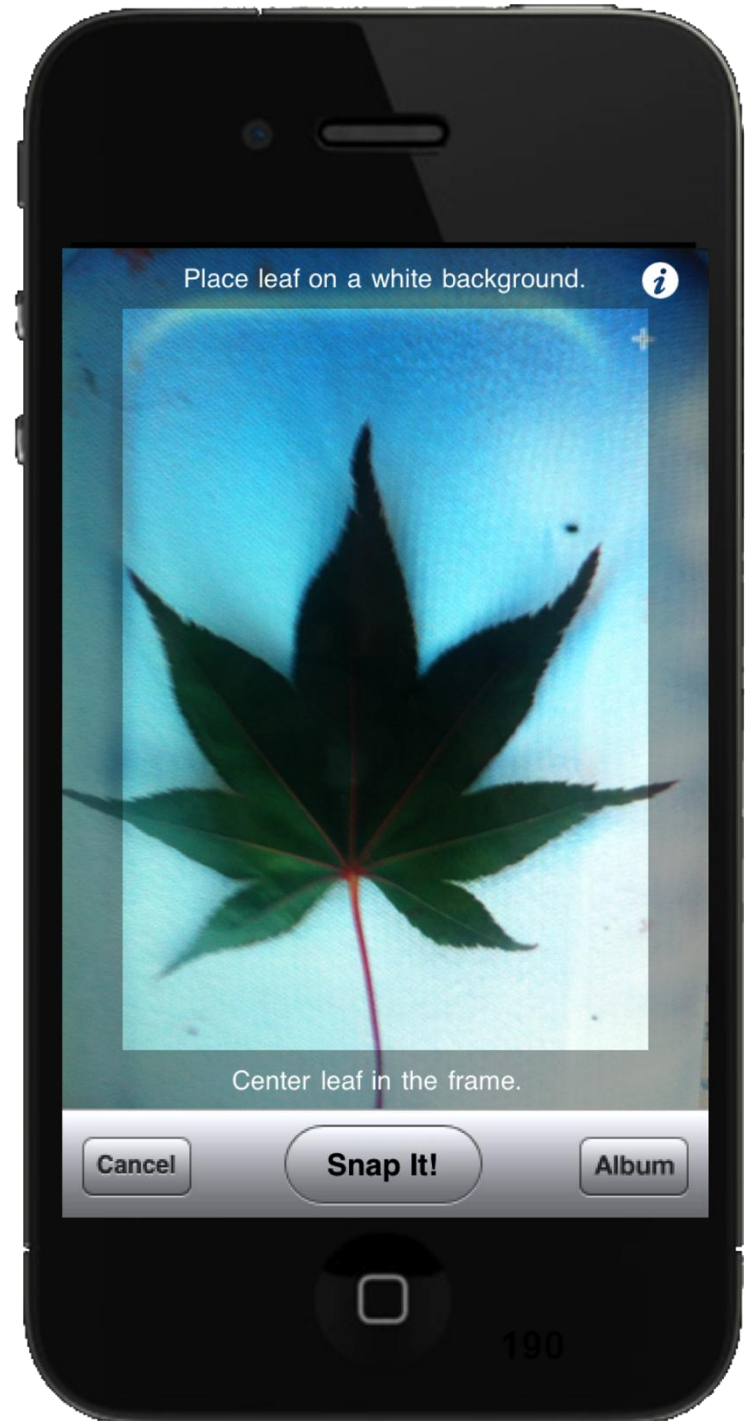
- that you can search and sort



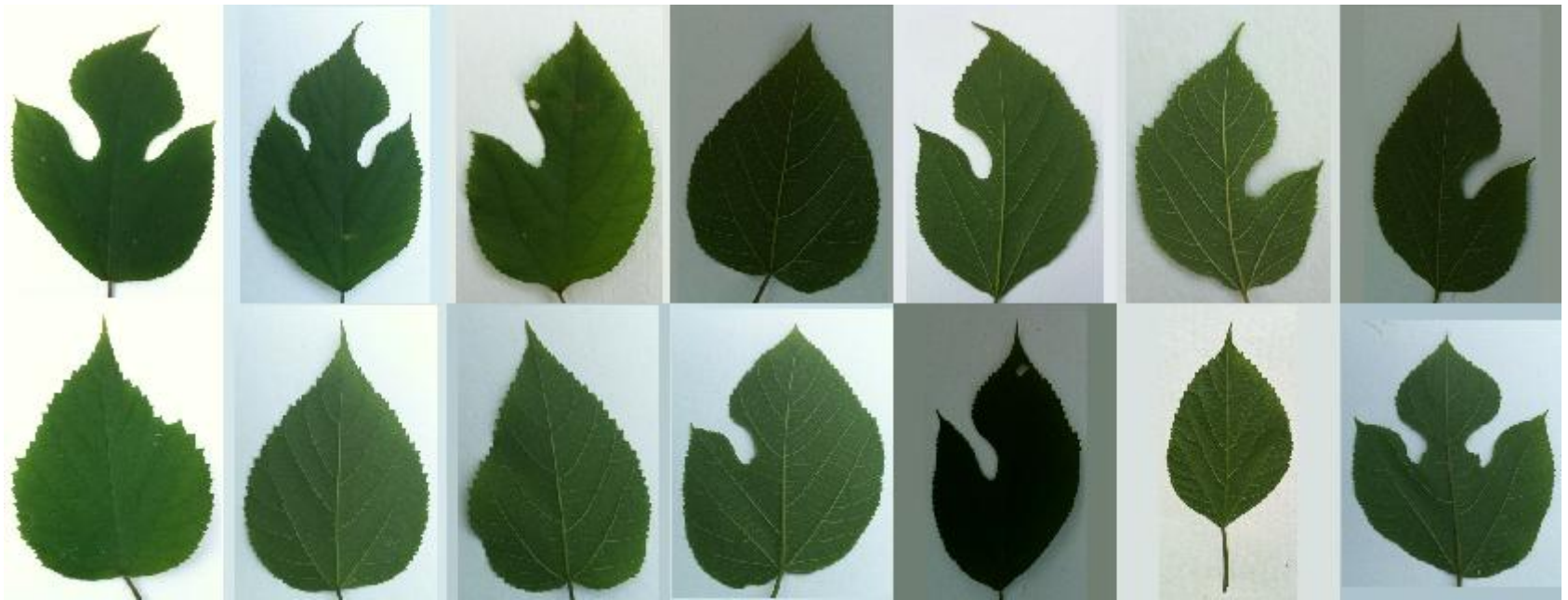


Like a normal field guide...

- that you can search and sort
- and with visual recognition



Large Intra-Class Variation



Images of Paper Mulberry (*Broussonettia papyrifera*)

What do iPhone Images Look Like?



Blurry, Not flat

What do iPhone Images Look Like?



Blurry, Not flat, Varying color, Shadows

What do iPhone Images Look Like?



Blurry, Not flat, Varying color, Shadows, No venation, Thin Structures

What do iPhone Images Look Like?



Blurry, Not flat, Varying color, Shadows, No venation, Thin Structures, White balance, Color splotches, ...

Classification

- Classifying whether the image is of a valid leaf
 - Of a single leaf
 - Placed on light
 - Un-textured background with no other clutter
- They employ a binary RBF SVM classifier applied to gist features (by LEAR).

Segmentation

Leaf Shape is Distinctive



5-lobed



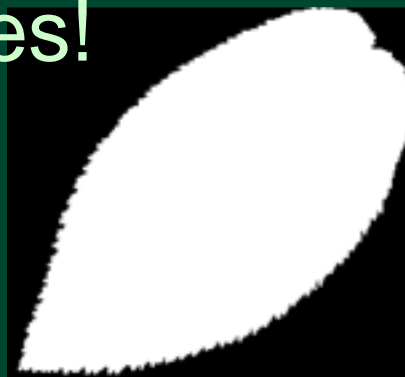
Use curvatures at

Smooth edges many scales Serrated edges

to distinguish leaves!



single-lobed



Segmentation in HSV Colorspace



Original Image
In Saturation-Value Space
(On white background)

We do this by estimating foreground and background color distributions in the saturation-value space of the SV colorspace.

Segmentation in HSV Colorspace



In Saturation-Value Space

Pixel-wise sum of two Gaussian Image Model:

$$p(x|\Theta) = \sum_{k=1}^2 \frac{1}{2} p(x|\mu_k, \Sigma)$$

Pixel label, given parameters

{foreground, background}

Mean color of class

Shared covariance

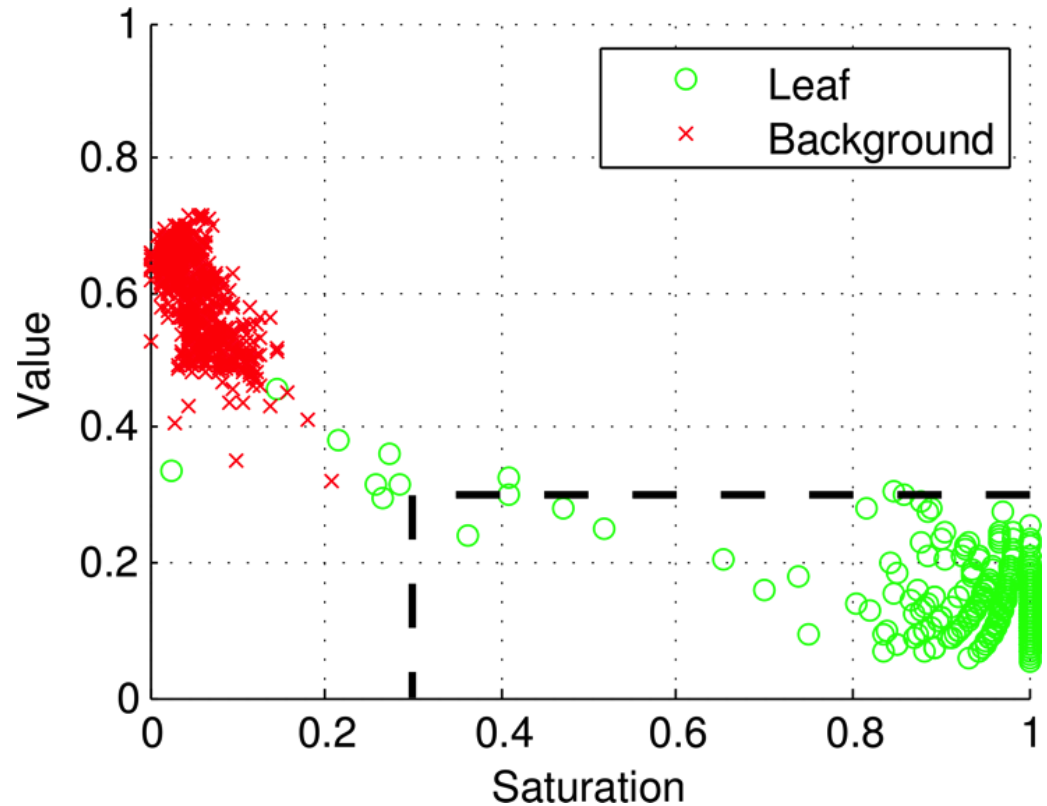
Hue is not useful because the background often has a greenish tinge due to reflections from the leaf or surrounding foliage

Segmentation in HSV Colorspace

Some difficulty with pine leaves → they employed pixel weighting



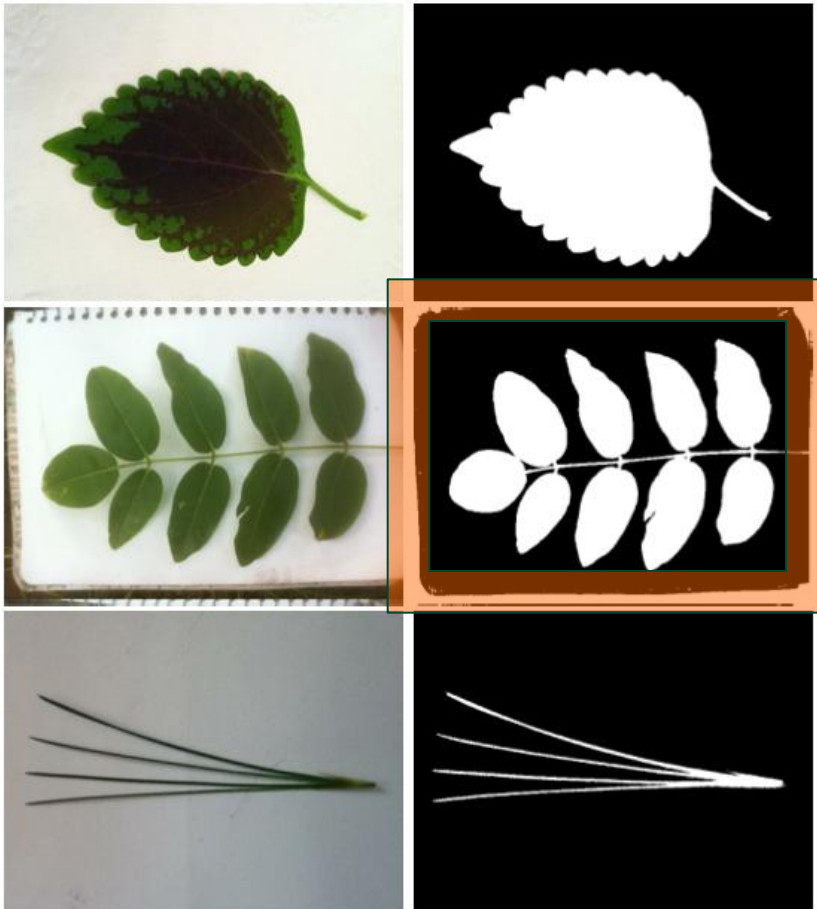
In Segmented Value Space



Expectation-Maximization (6-7 iterations)

Use downsampeled version during EM

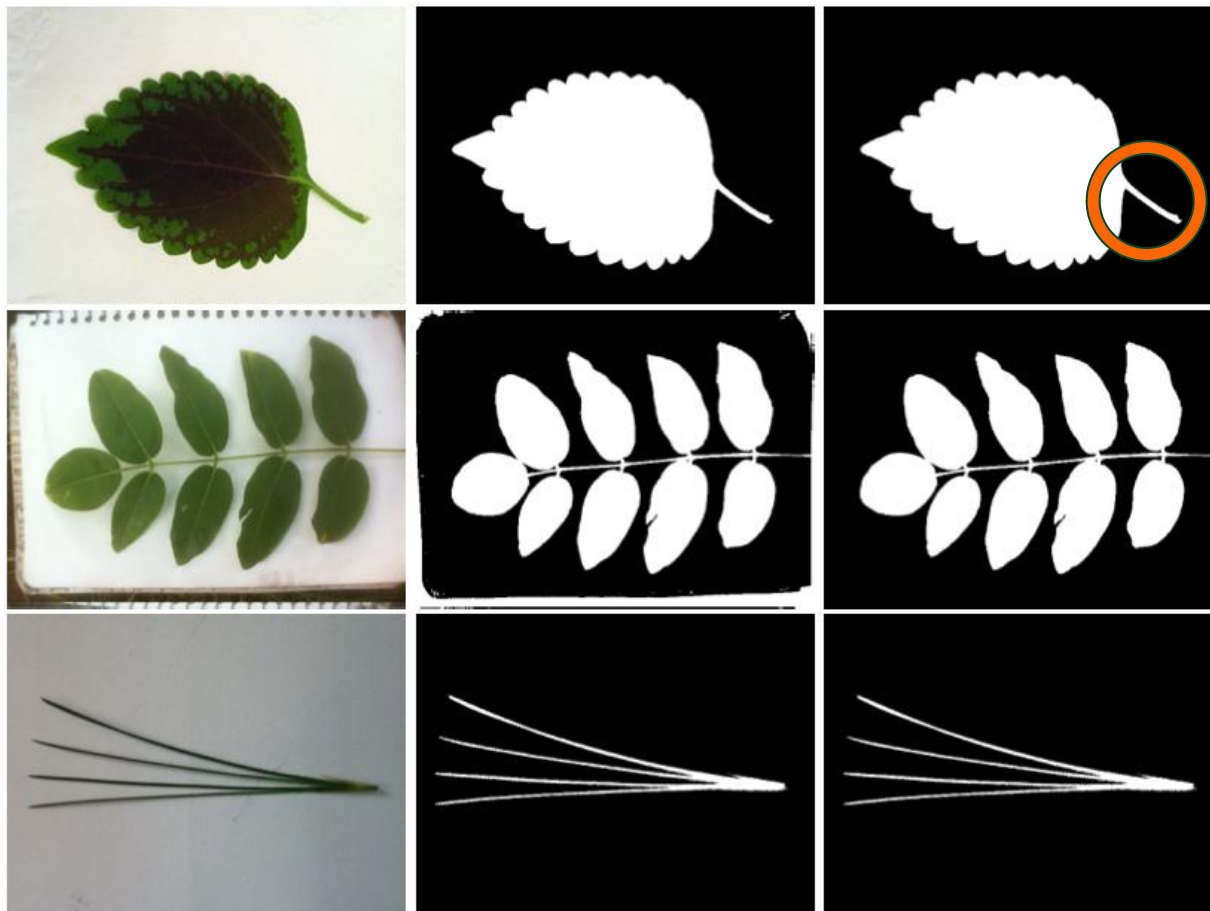
Segmentation Results



Original

Initial Result
(60 ms)

Segmentation Results

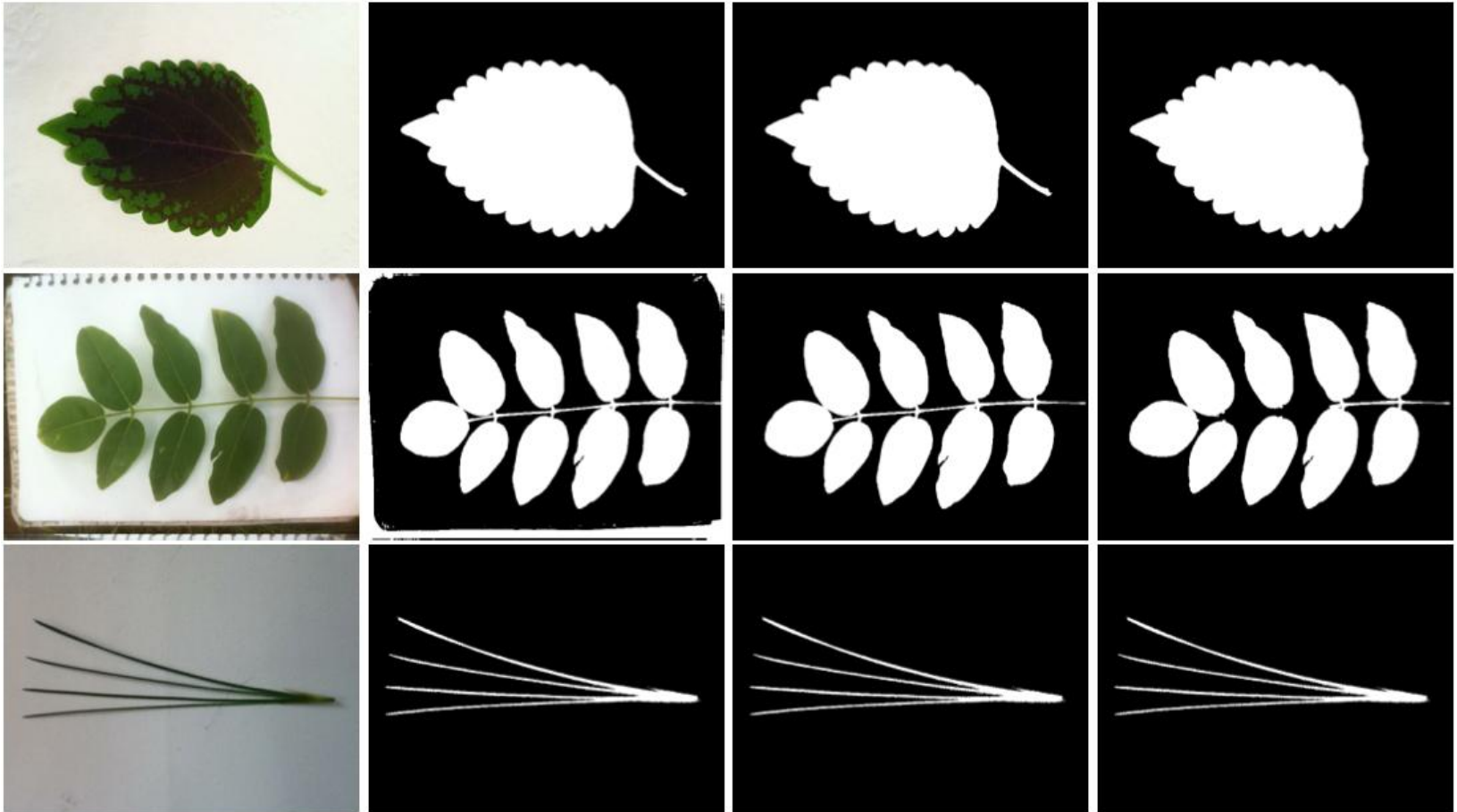


Original

Initial Result
(60 ms)

Rem. False
Positives (6 ms)

Segmentation Results



Original

Initial Result
(60 ms)

Rem. False
Positives (6 ms)

Remove
Stem (36 ms)
Morphological operations

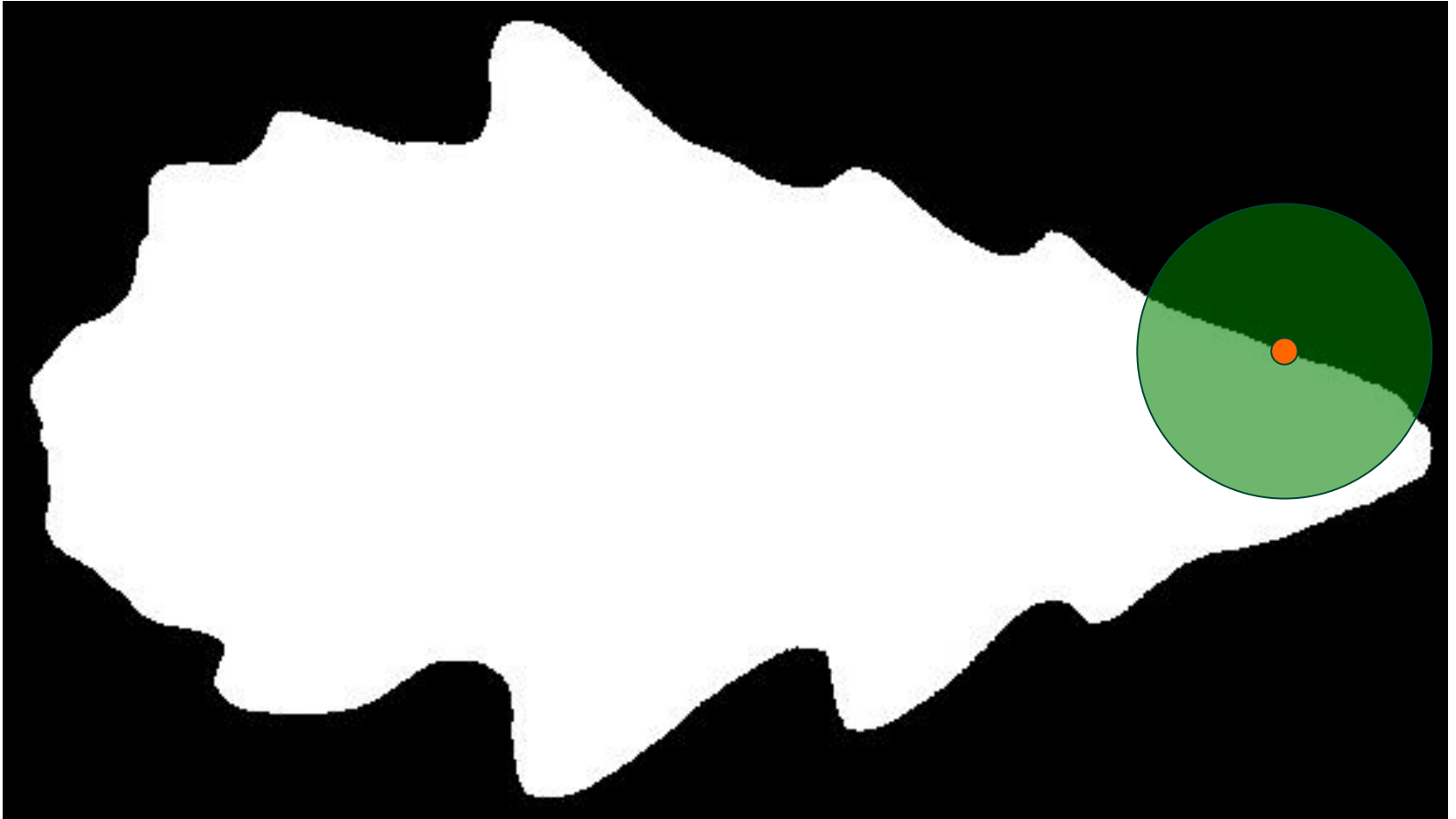
Computing Curvature

- Rotations?
- Segmentation Errors?
- Scale Changes?
- Complex Boundaries?
- Axis Alignment?



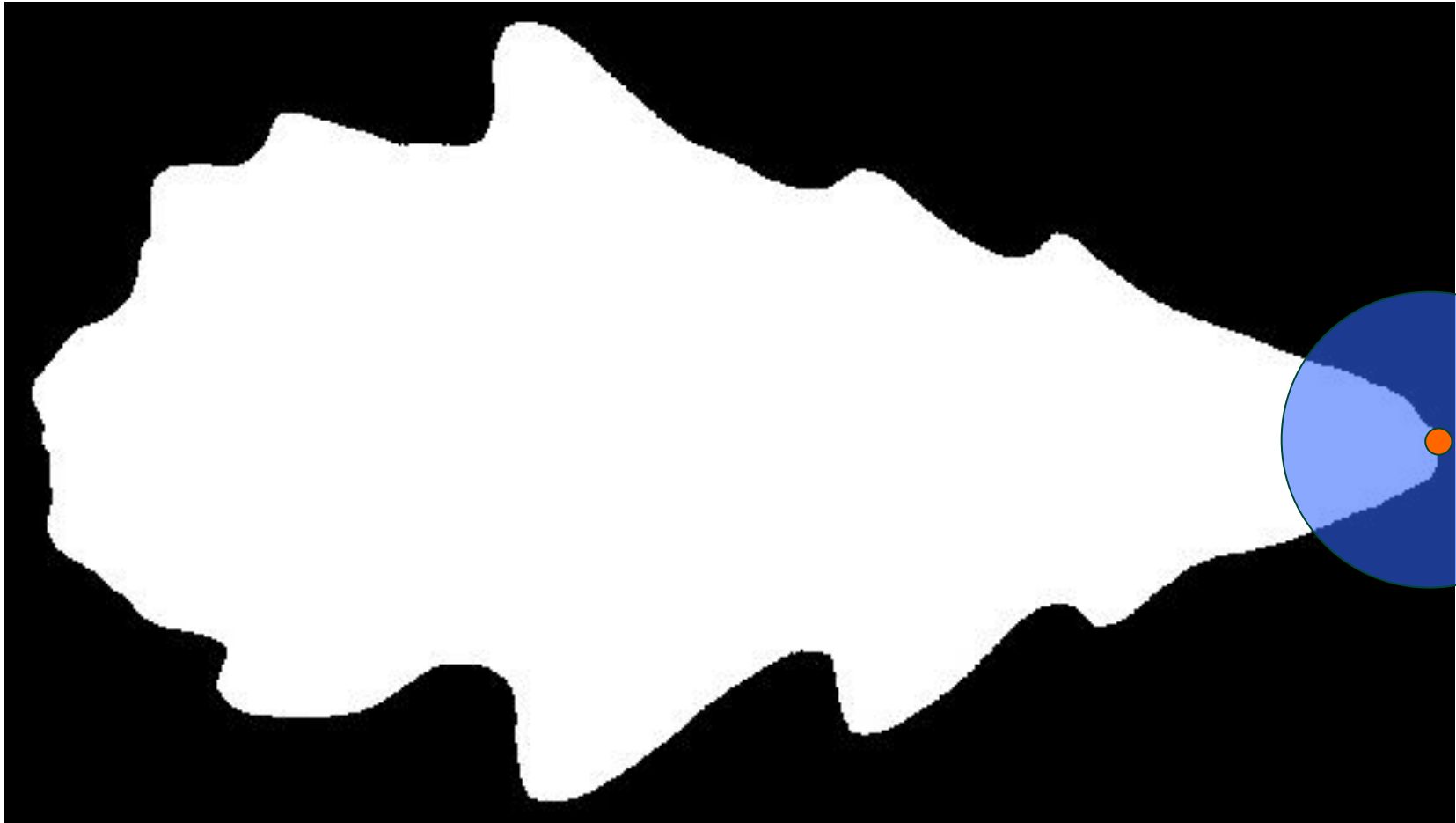
Differential measures: not robust on discrete grids
And amplify noise

Curvature Using Integral Measures



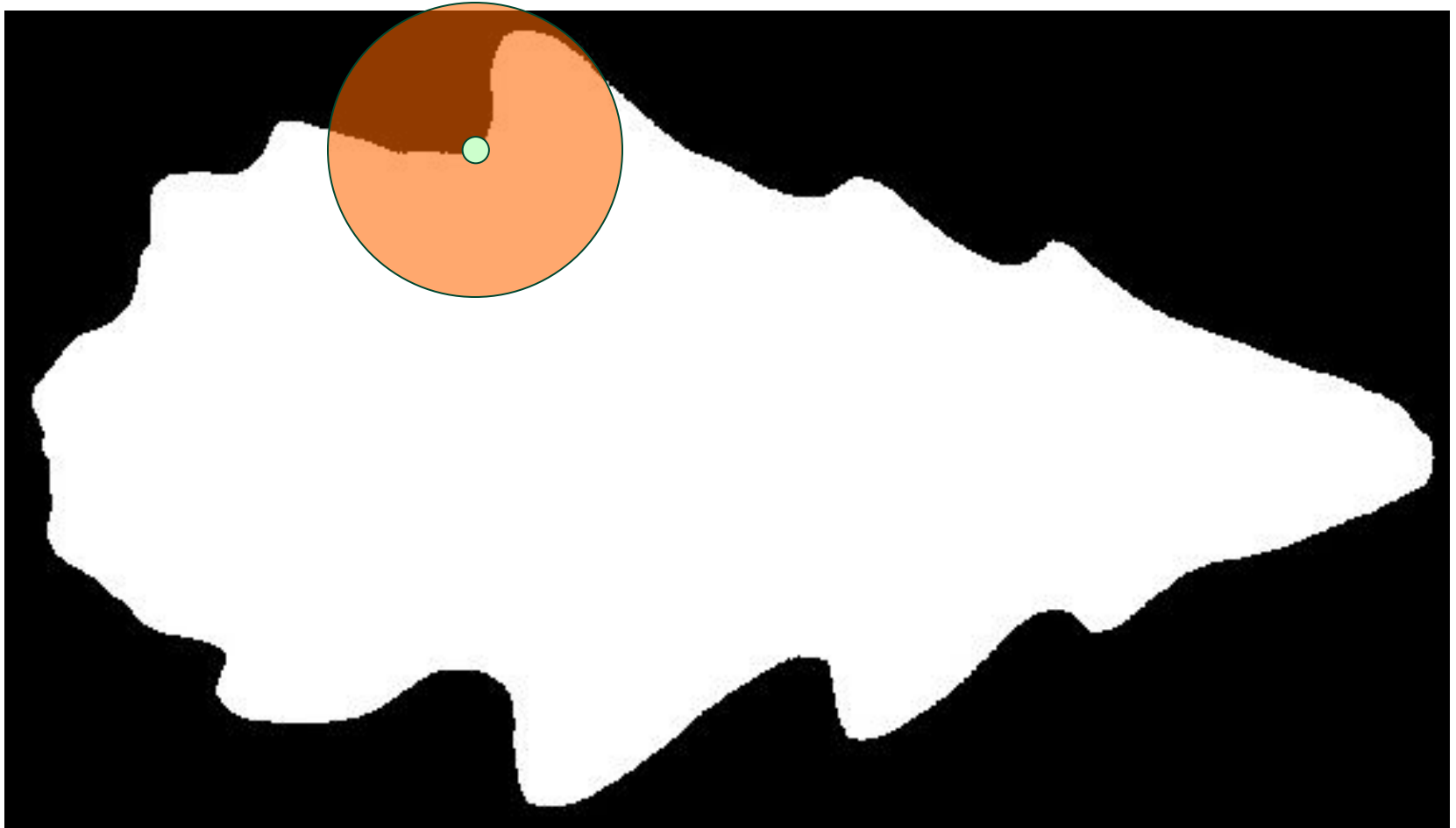
Curvature = (white pixels in circle)/area = 0.5 (straight)

Curvature Using Integral Measures



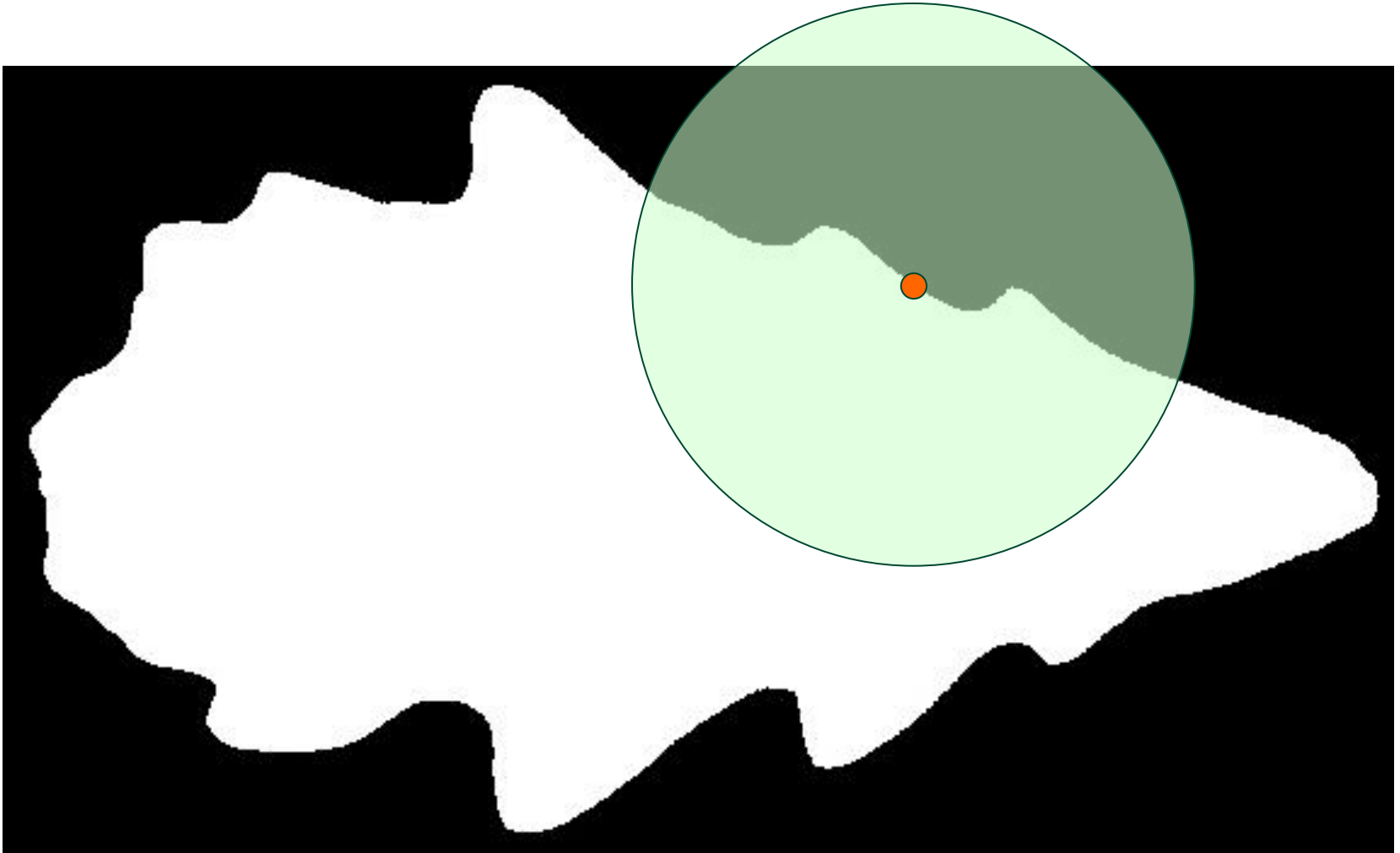
Curvature = (white pixels in circle)/area = 0.2 (convex)

Curvature Using Integral Measures



Curvature = (white pixels in circle)/area = 0.8 (concave)

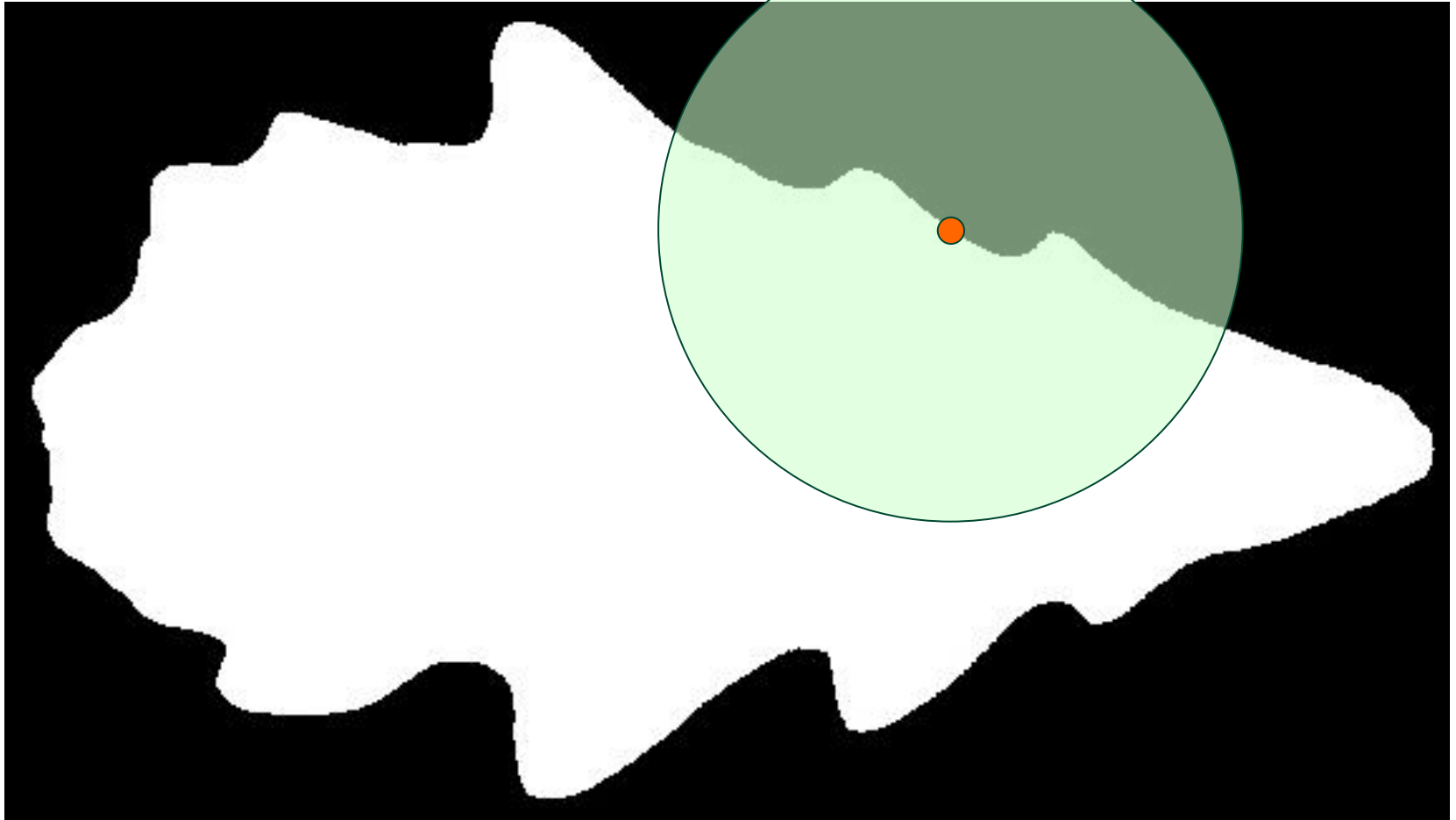
Curvature Using Integral Measures



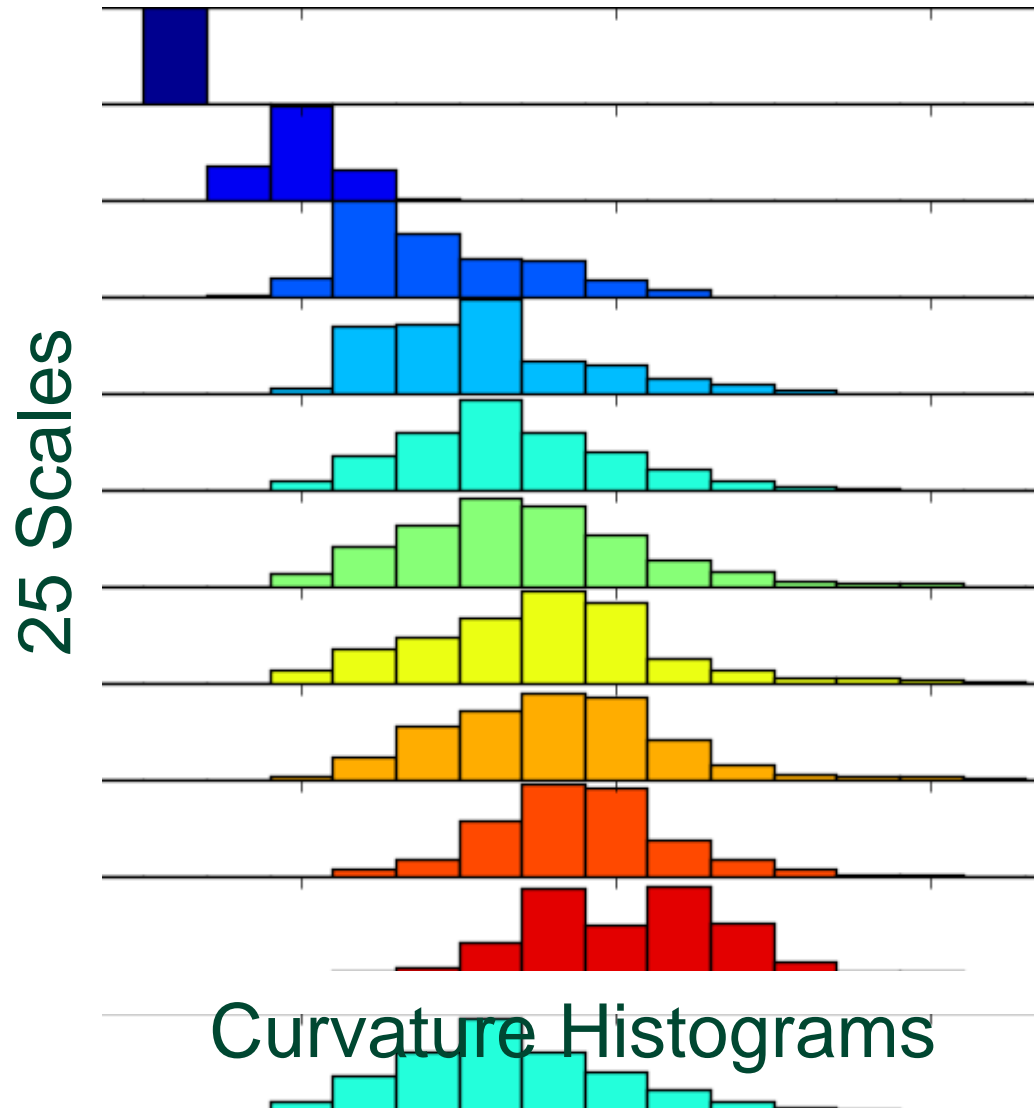
Curvature = (white pixels in circle)/area = 0.5

Build Histogram of Curvatures (HoCS)

compute histograms of the curvature values at each scale



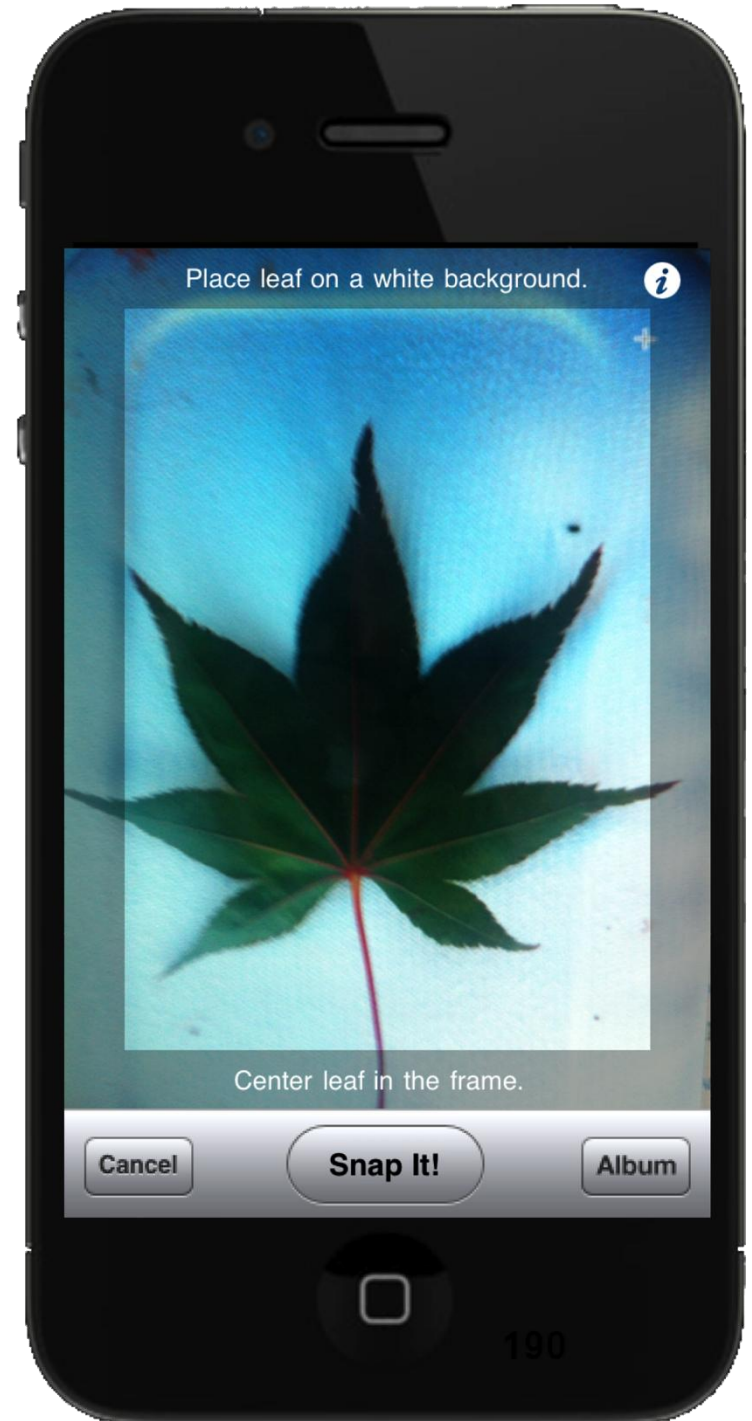
Histograms of Curvature over Scale



Total time: 0.11s

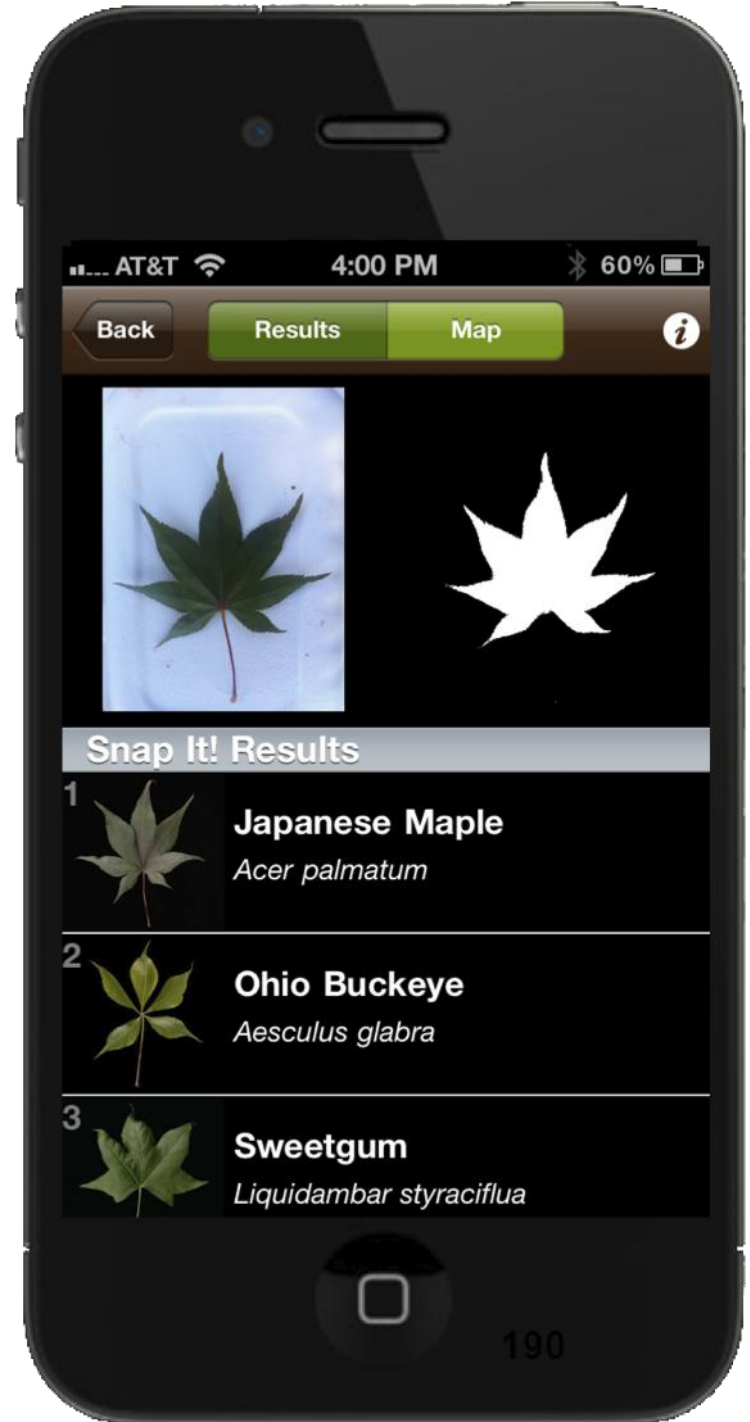


- Upload image
- Perform recognition (5.4s)
 - Nearest neighbor classifier
- Get ranked results

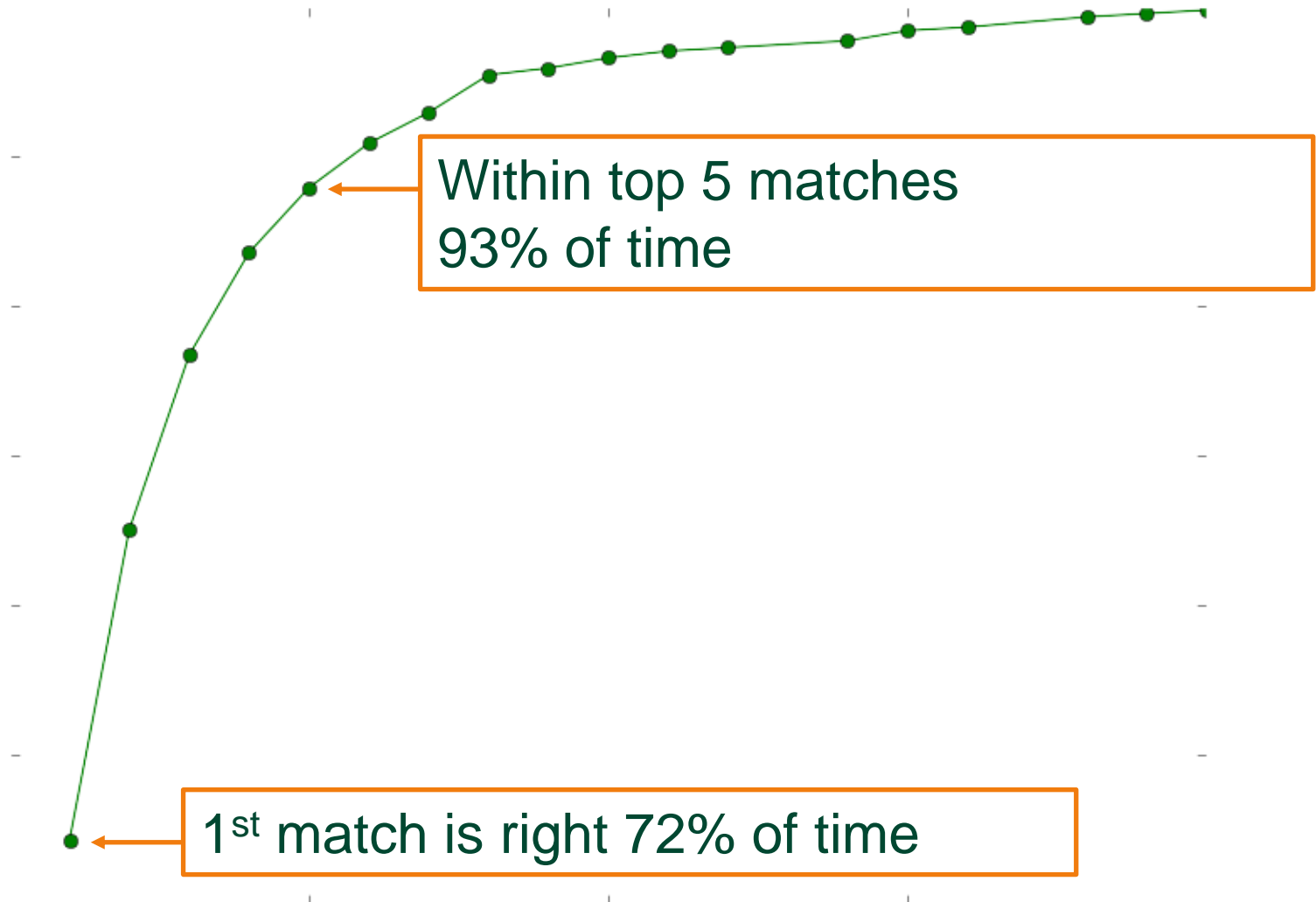




Which species is it?

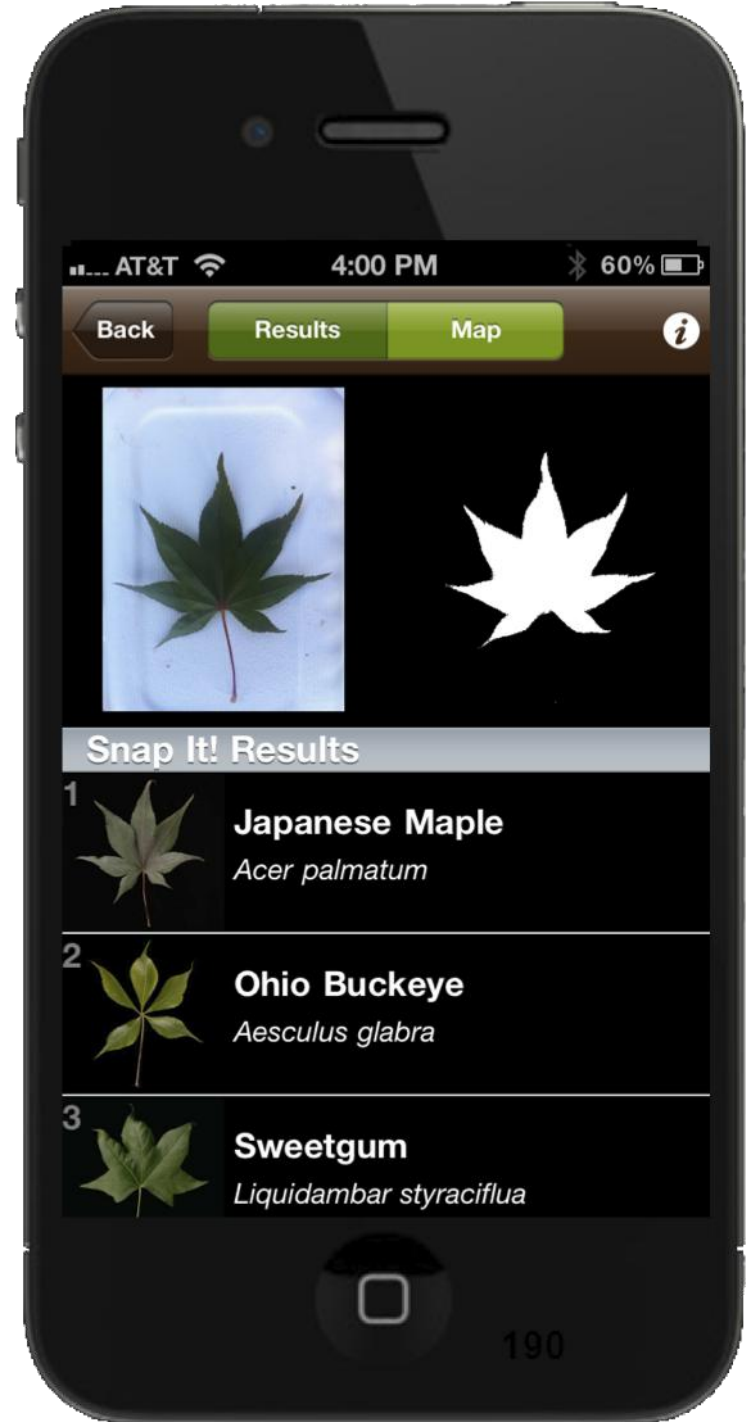


Accuracy on the Trees of the Northeast





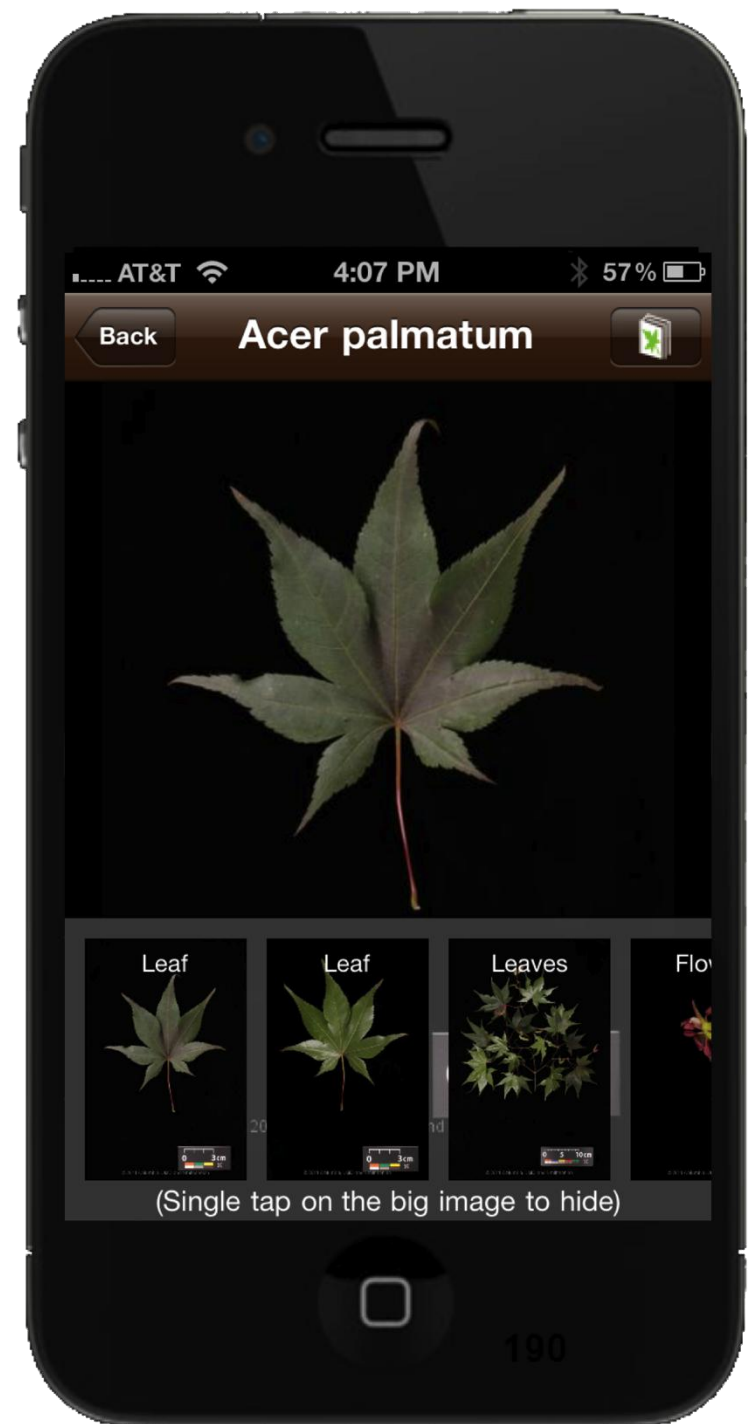
Which species is it?





Which species is it?

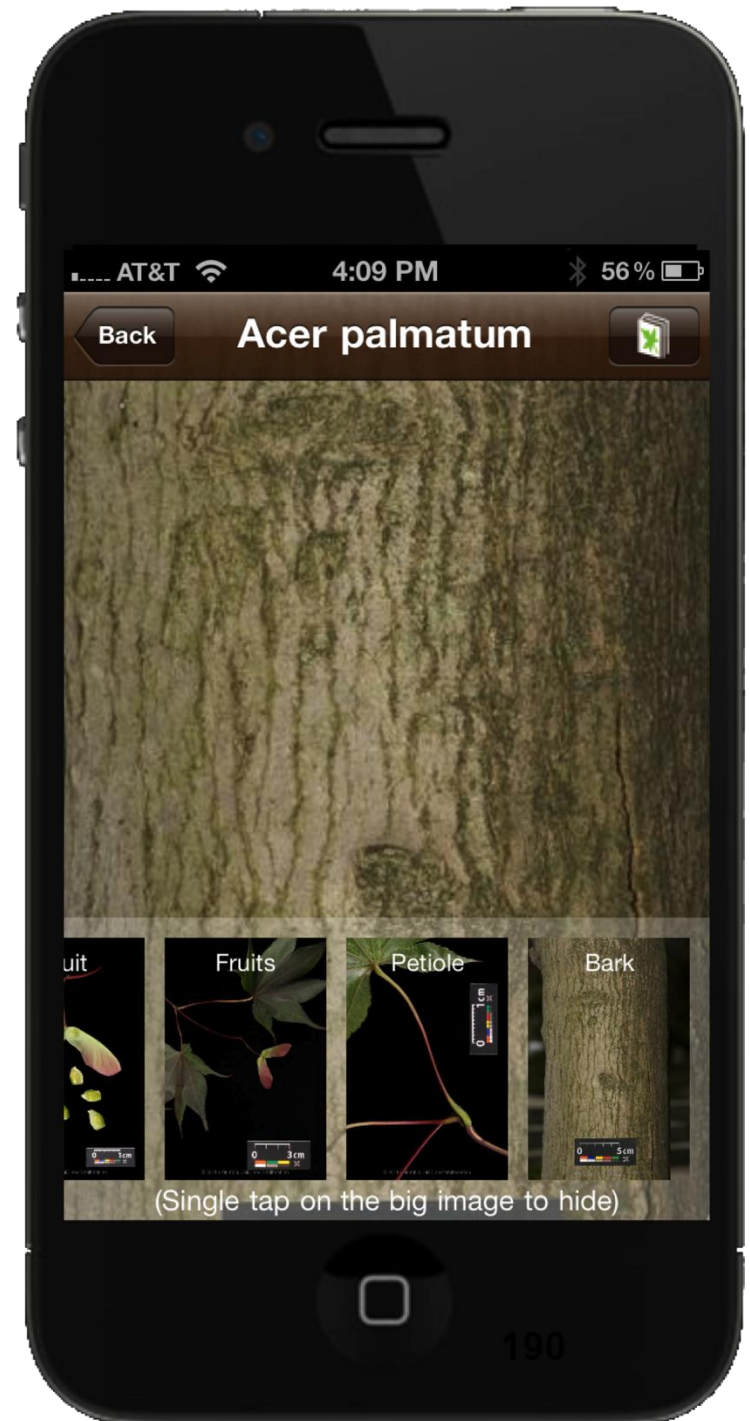
- Explore the images in the app





Which species is it?

- Explore the images in the app
 - Including the bark and stem





Which species is it?

- Explore the images in the app
 - Including the bark and stem
- Read the text descriptions





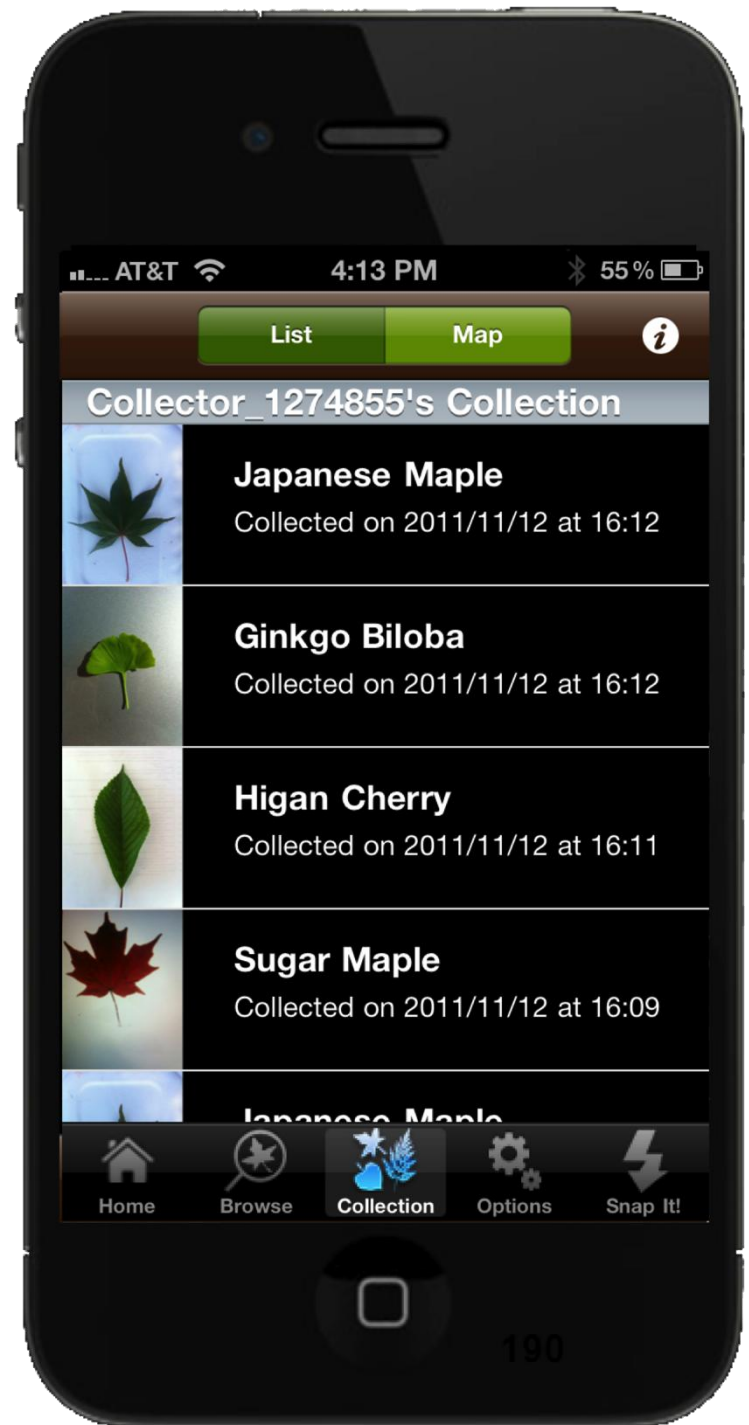
Which species is it?

- Explore the images in the app
 - Including the bark and stem
- Read the text descriptions
- Once confident, label it!





Look back through your collection...





Look back through your collection...

- Including the location!





- Nearly 1 million downloads
 - 40k new users per month
 - 100k active users
- 1.7 million images taken
 - 100k new images/month
 - 100k users with > 5 images
- Users from all over the world
- Botanists, educators, kids, hobbyists, photographers, ...





- very fast, suitable for use in an interactive application
- adapt to major sources of color variability such as lighting changes and natural variations in leaf color



- Nearly 1 million downloads
 - 40k new users per month
 - 100k active users
- 1.7 million images taken
 - 100k new images/month
 - 100k users with > 5 images
- Users from all over the world
- Botanists, educators, kids, hobbyists, photographers, ...

guardian.co.uk

The New York Times

The Washington Post

WIRED

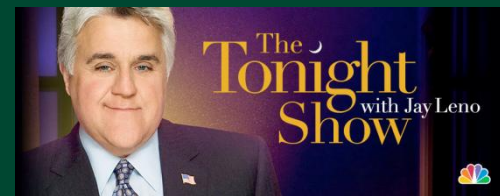
engadget

Science

STUDIO 360

TechCrunch

GIZMODO



Lots of Future Directions



Education
and Outreach



Tracking
Biodiversity



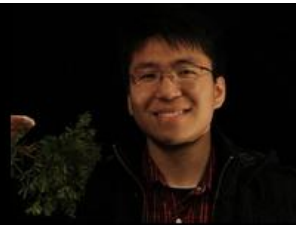
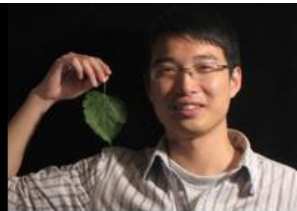
Discovering
New Species



leafsnap

- Apps Dataset Code available at leafsnap.com
- Plant images in apps taken by FindingSpecies.org

volunteers



Thank You

