Introduction to Computer Vision

Danna Gurari
University of Colorado Boulder
Fall 2024

https://dannagurari.colorado.edu/course/recent-advances-in-computer-vision-fall-2024/

Today's Topics

- Computer vision: origins
- What makes computer vision hard?
- Research in computer vision
- Course logistics

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- What makes computer vision hard?
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Computer Vision: Computers that “See”

Self-driving cars

Exploration on Mars

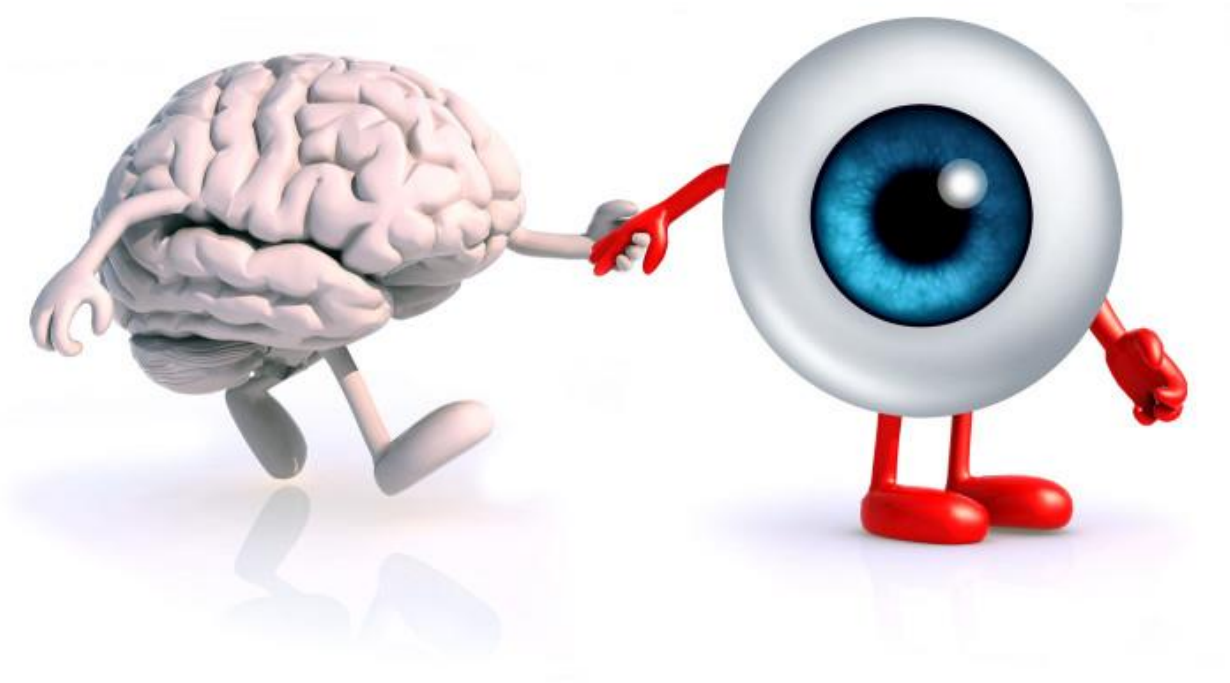
Guided surgery

Visual assistance for people who are blind

Security

Origins of Computer Vision

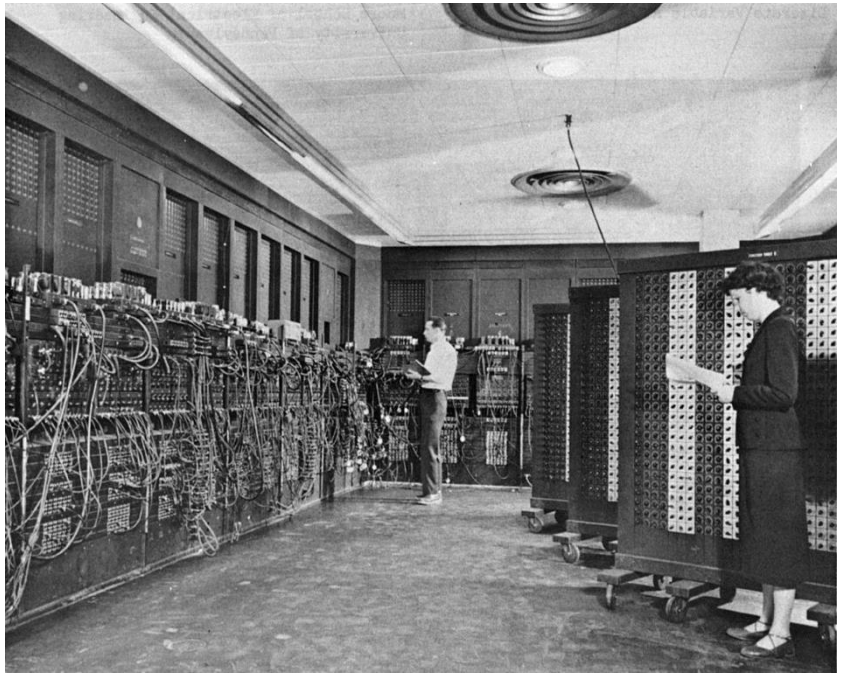
Emulating the basic ingredients of sight:



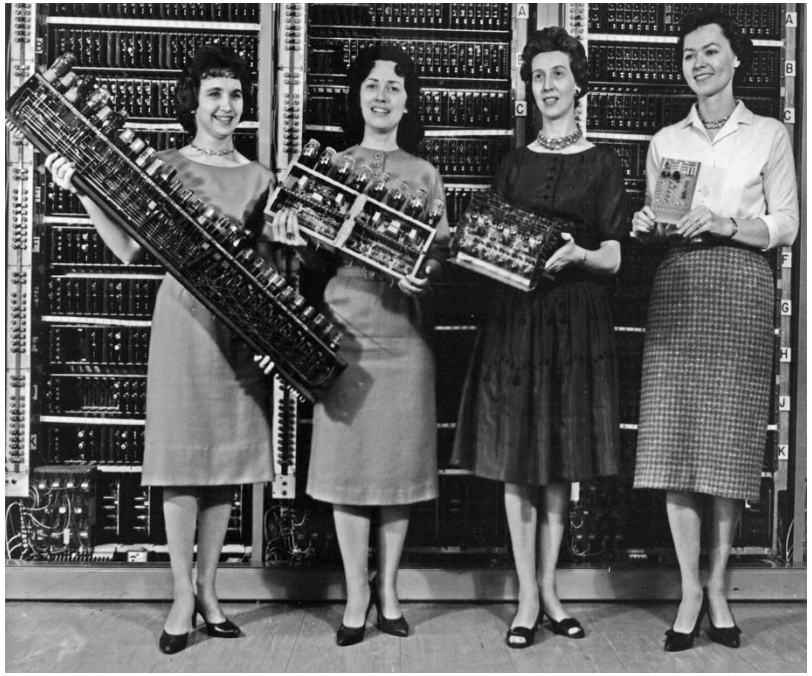
Origins of Computer Vision

1945

First programmable machine



ENIAC (Electronic Numerical Integrator and Computer) created during World War II
(could compute 5,000 additions in one second)



First programmers

Origins of Computer Vision

1945 1950

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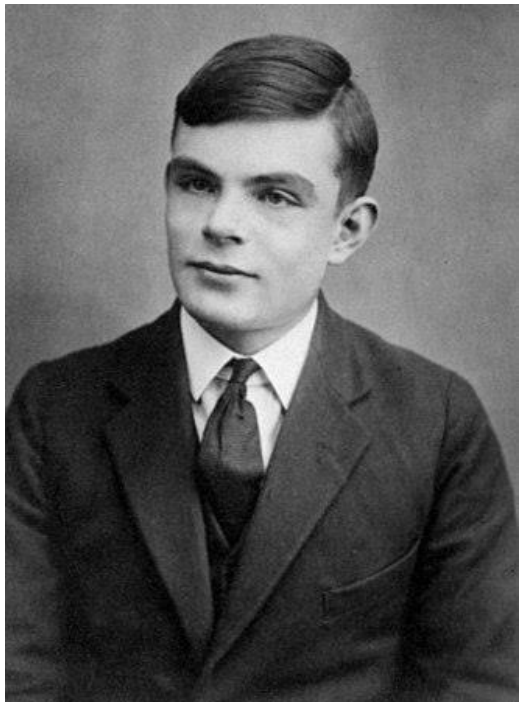
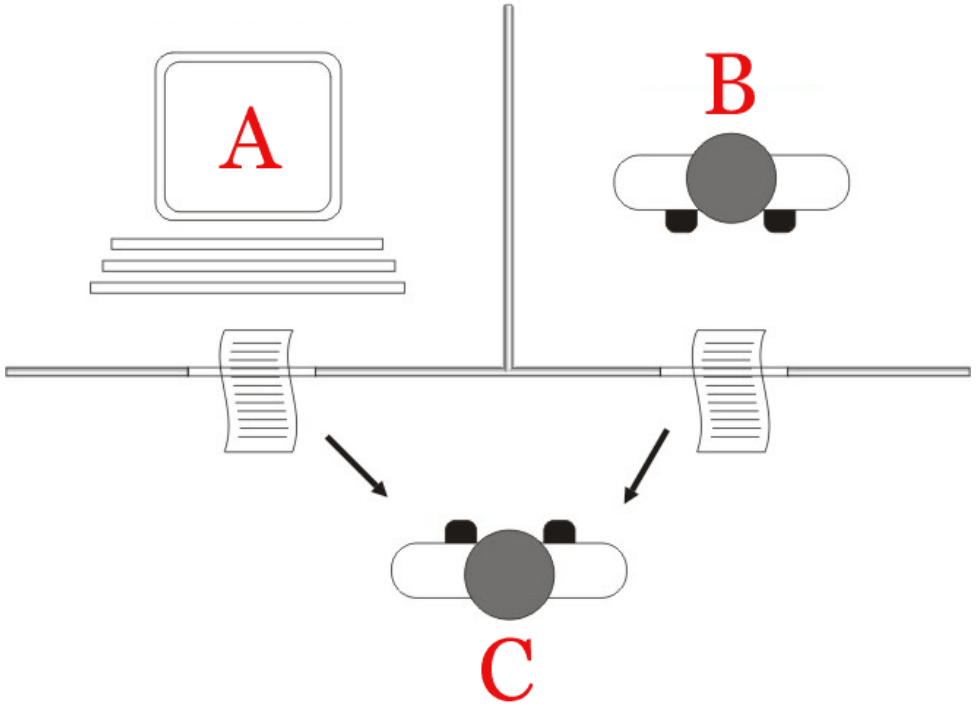
Turing test



Alan Turing
(1912-1954)



Turing Test: can “C” decide whether text responses come from a machine or human

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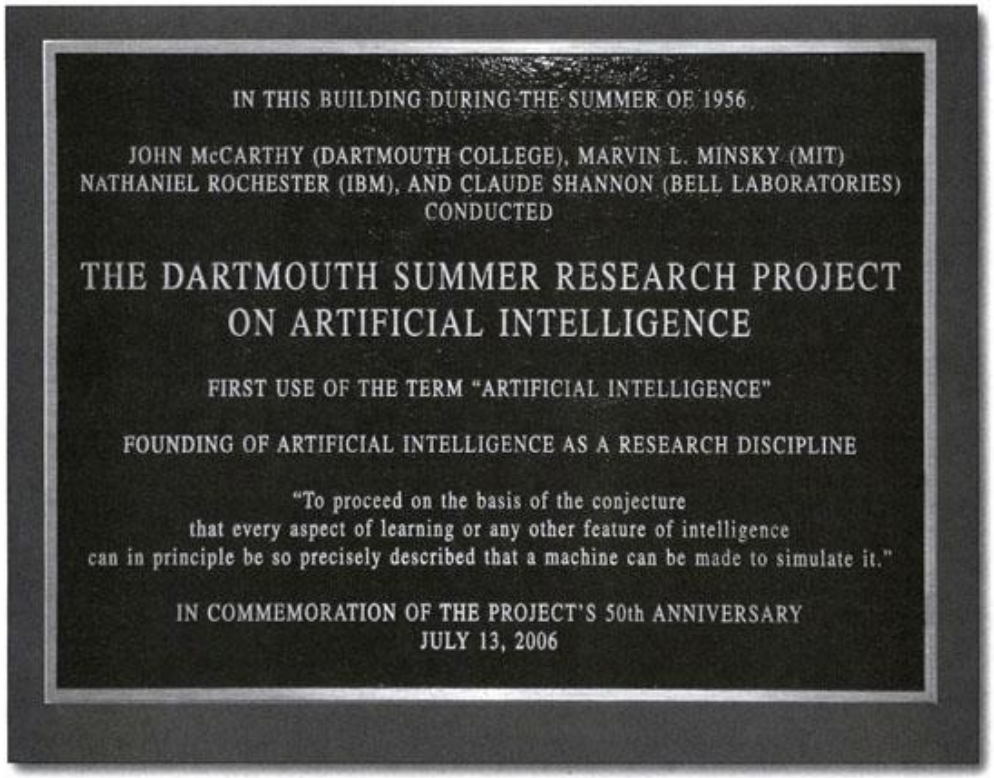
AI birth



"Artificial intelligence" established as a field at a workshop

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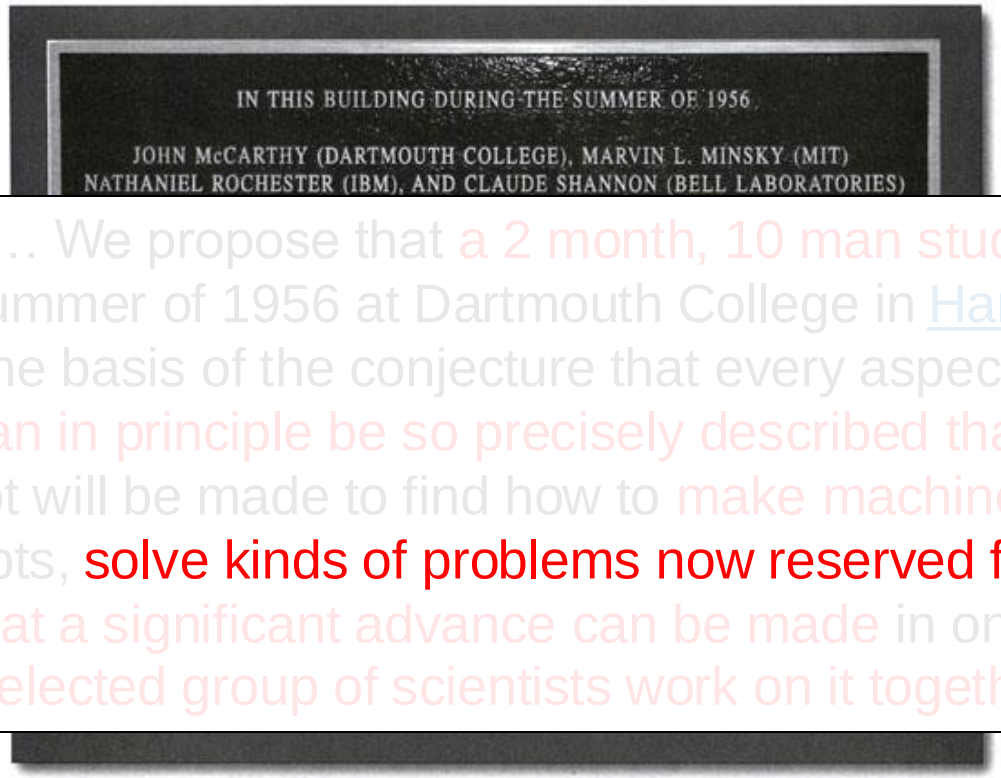

Workshop Proposal: "… We propose that a 2 month, 10 man study of artificial intelligence be carried out during the summer of 1956 at Dartmouth College in Hanover, New Hampshire. The study is to proceed on the basis of the conjecture that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it. An attempt will be made to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves. We think that a significant advance can be made in one or more of these problems if a carefully selected group of scientists work on it together for a summer…"

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Origins of Computer Vision

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Turing test

AI birth

What human intelligence might computers imitate?

Origins of Computer Vision

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Turing test

AI birth

First digital image

176 x 176 pixels

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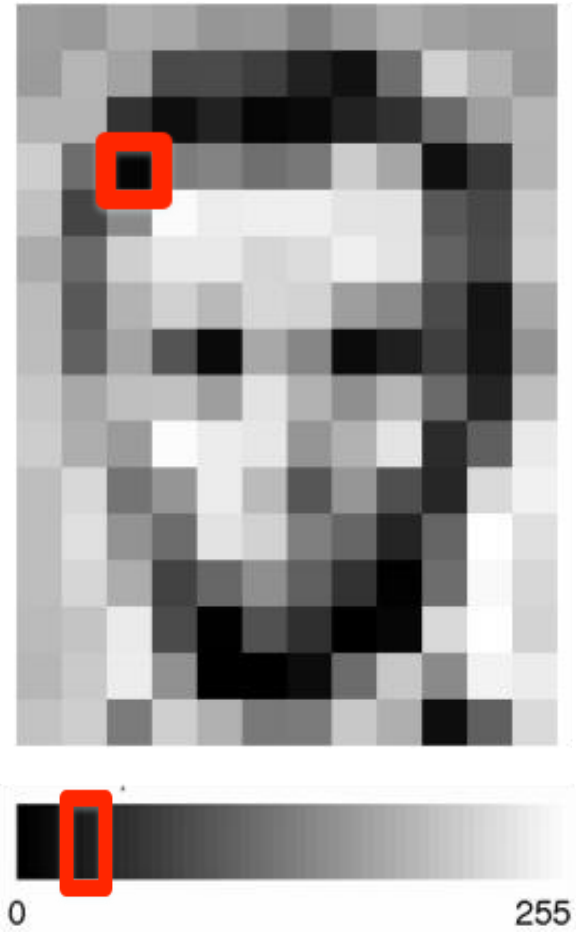

What a Computer Sees:

https://ai.stanford.edu/~syyeung/cvweb/tutorial1.html

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155	182	163	74	75	62	33	17	110	210	180	154
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206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
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199	168	191	193	158	227	178	143	182	106	36	190
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190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
190	214	173	66	103	143	96	50	2	109	249	215
187	196	235	75	1	81	47	0	6	217	255	211
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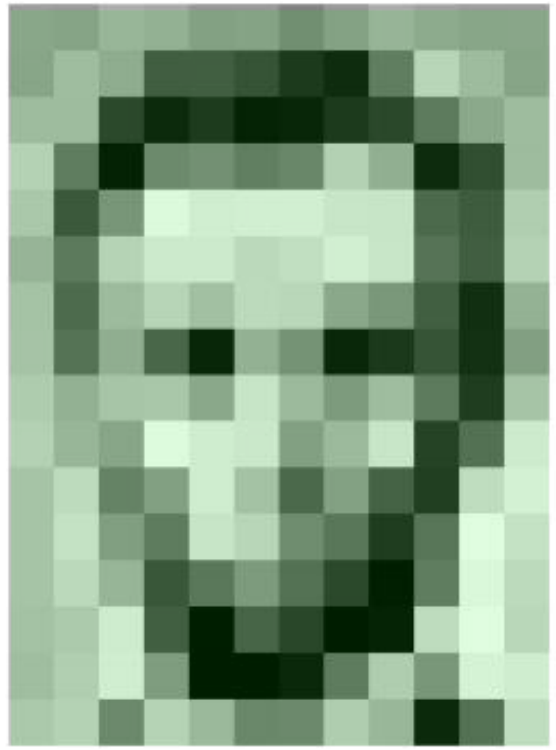
195	206	123	207	177	121	123	200	175	13	96	218



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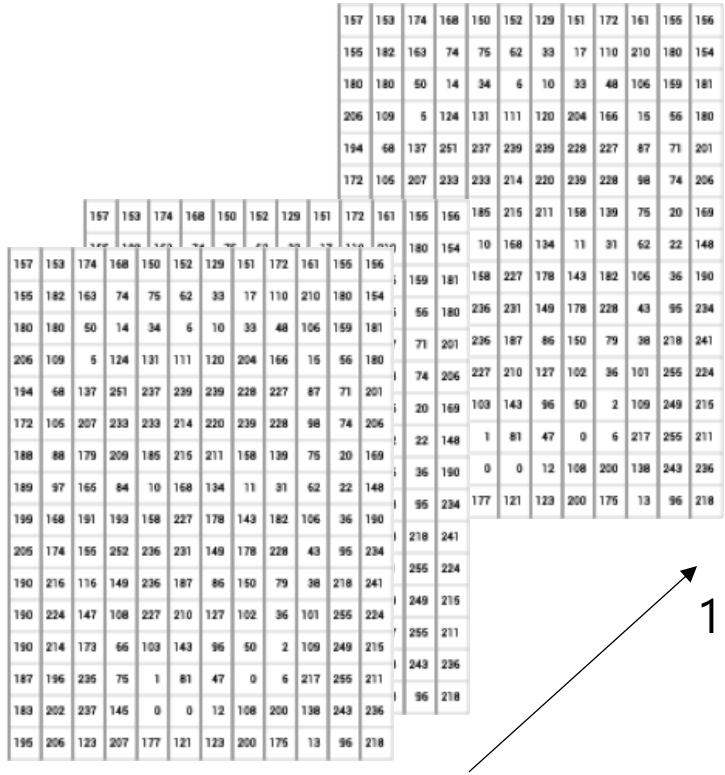
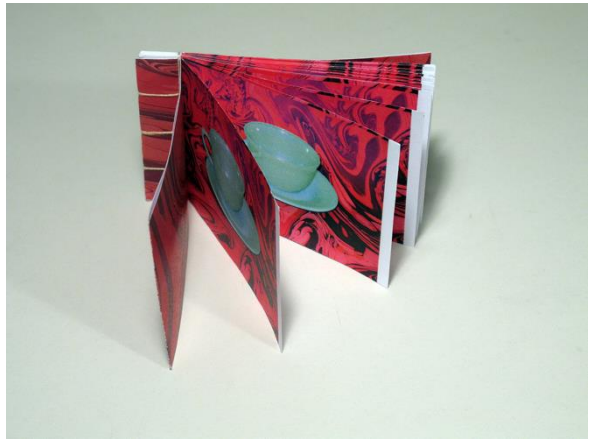


1 hour

Time 1

What a Computer Sees:

Analogous to (for video):



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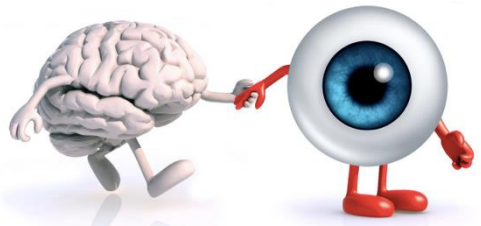

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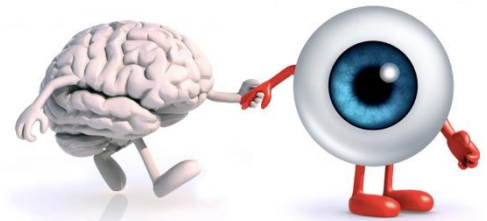

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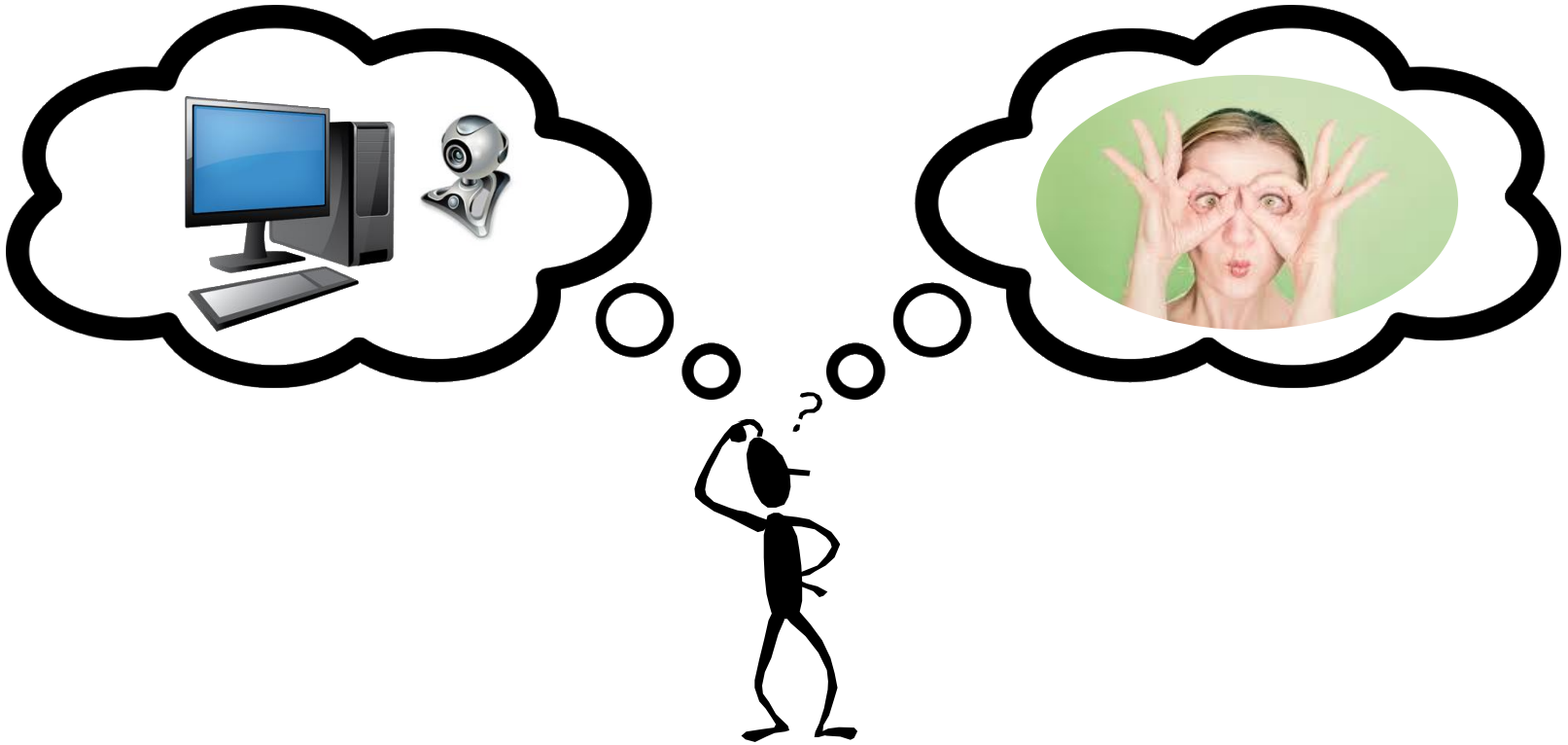
Turing Test: design “computer vision” that is indistinguishable from “human vision”



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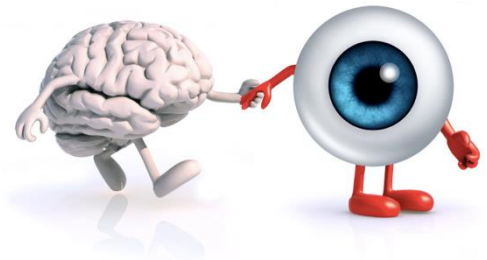

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What is this?
- A picture of a person

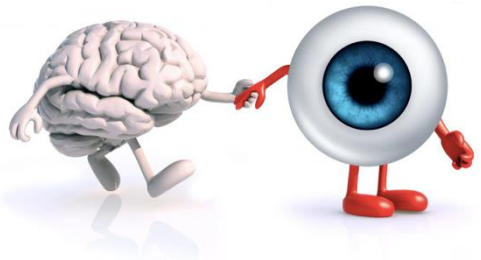
Could you describe this person?
- Long face
- Angular jaw
- Has a beard

Who is this person?
- Abraham Lincoln

Is this person happy?
- I am not sure.

Is this person attractive?
- ~70% of people would say “yes”

Origins of Computer Vision



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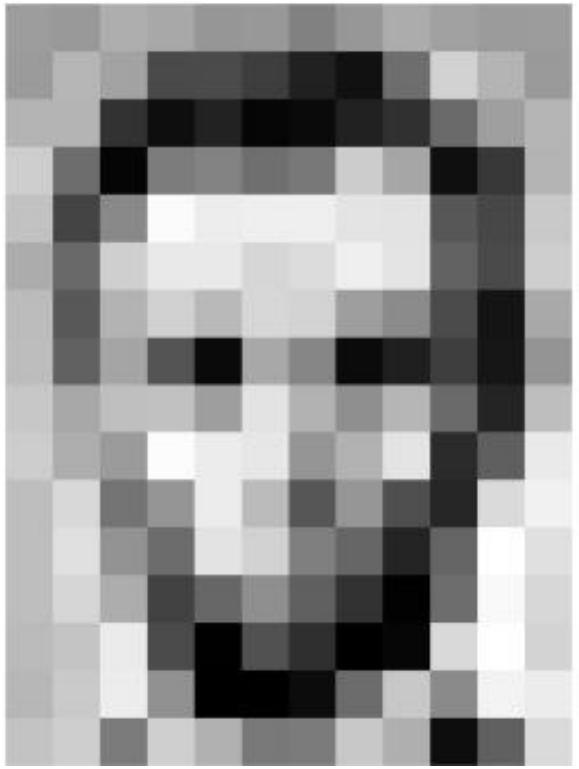

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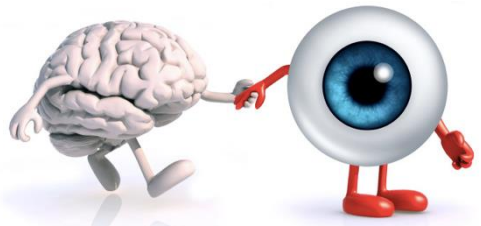
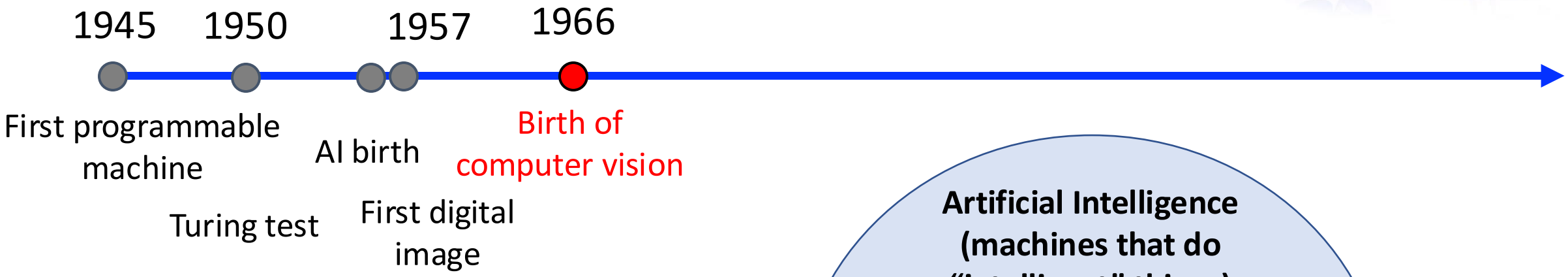
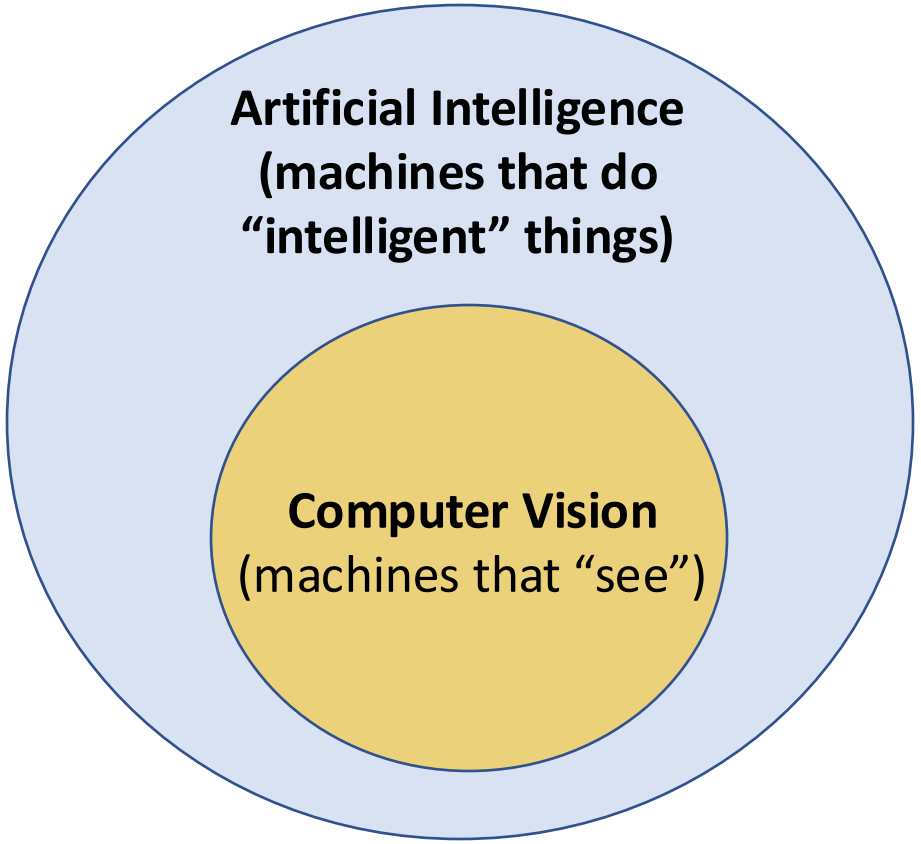


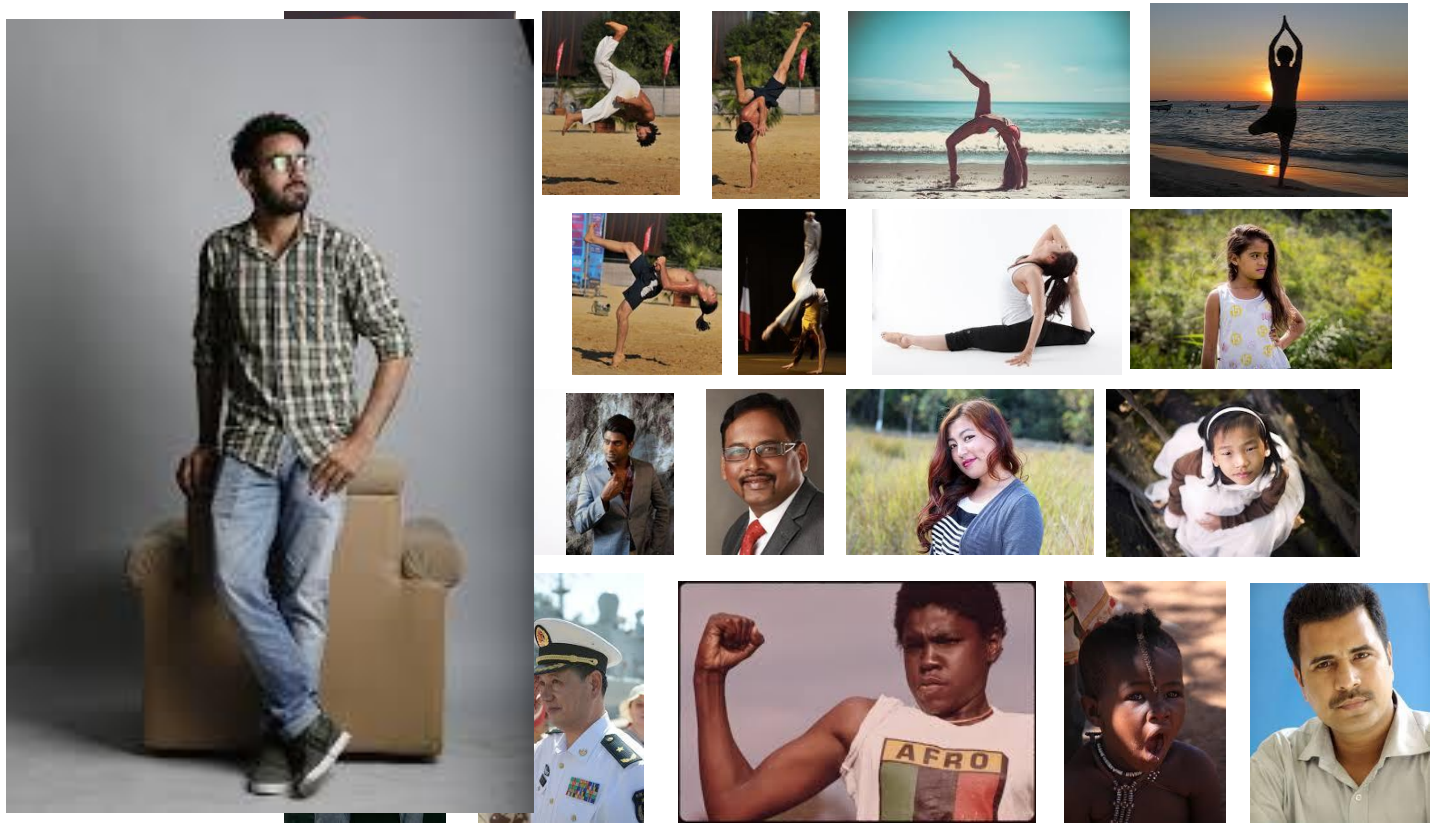




Today's Topics

- Computer vision: origins
- What makes computer vision hard?
- Research in computer vision
- Course logistics

Class Discussion: How Would You Program a Computer to Answer “Is a Person in the Image?”



Key Challenge: Replicate Human Vision for So Much Variation for **So Many Tasks**!

- Object recognition
- Scene classification
- Attribute labeling
- Object detection
- Segmentation
- Image Captioning
- Visual Question Answering
- Activity/Event Recognition
- Object Tracking
- Subjective Problems
- And more…

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e.g., take a picture of an object and find where to buy it

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Kitchen

Store

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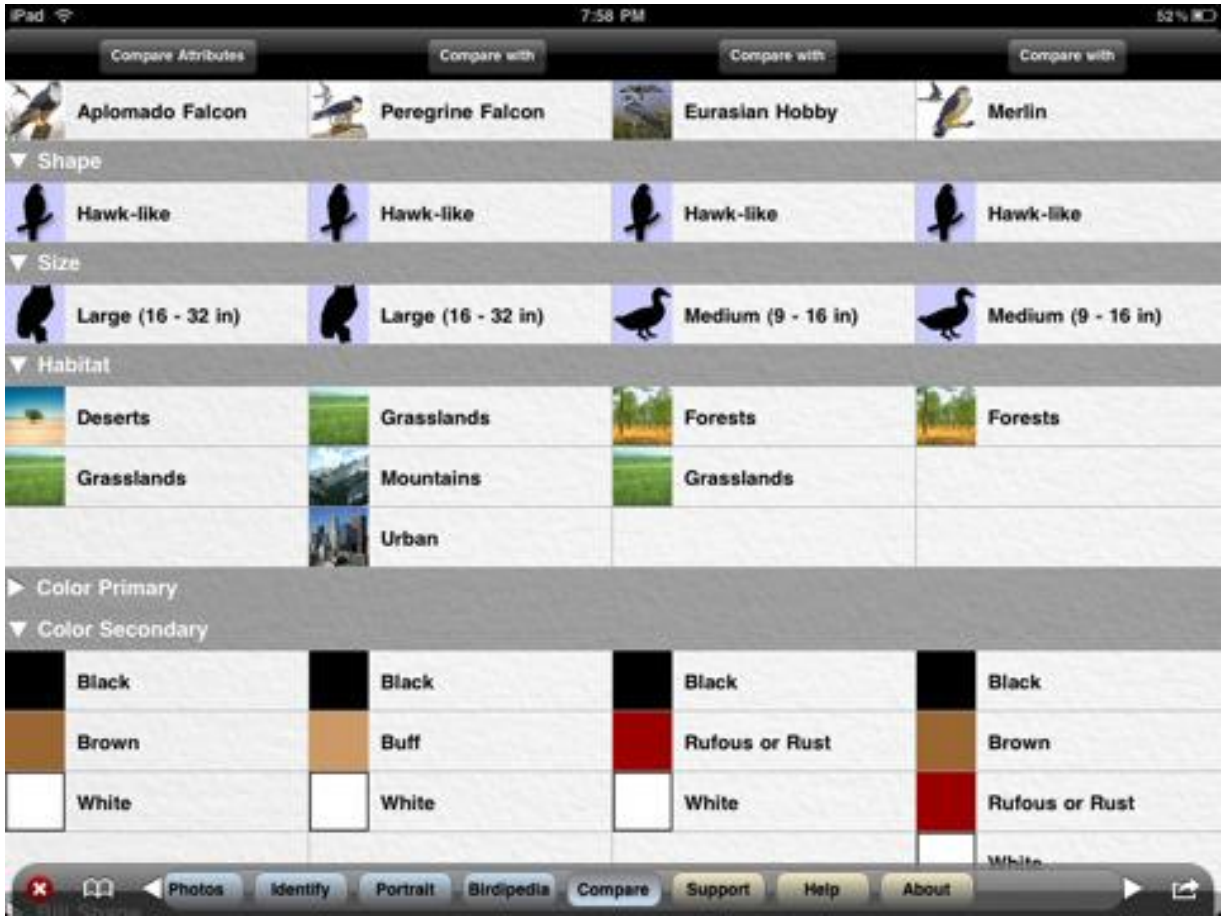

e.g., describe a bird to learn what type it is

Demo: https://www.youtube.com/watch?v=UPcz9Y17iCc

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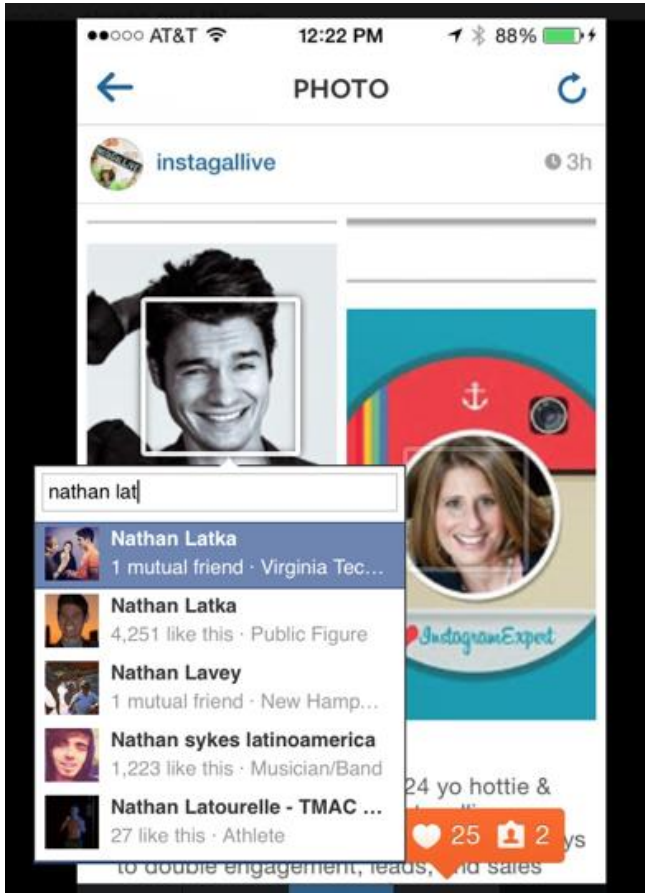

e.g., detect faces to tag

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e.g., rotoscoping
https://www.starnow.co.uk/ahmedmohammed1/photos/4650871/before-and-after-rotoscopinggreen-screening

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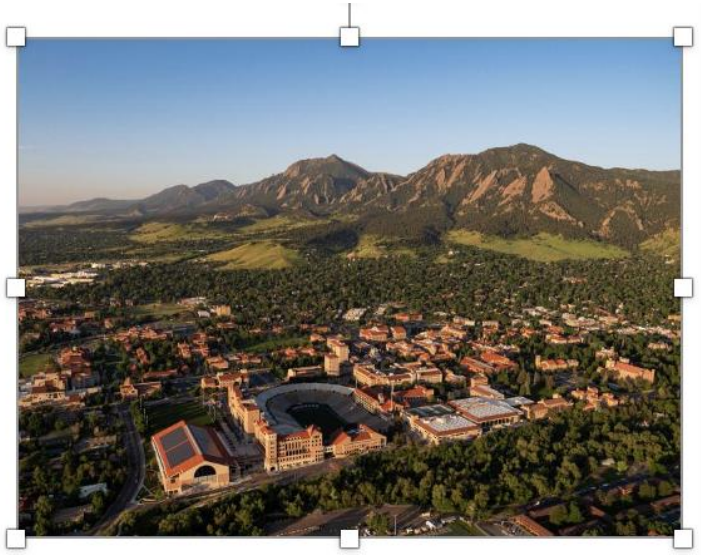

e.g., Microsoft Power Point

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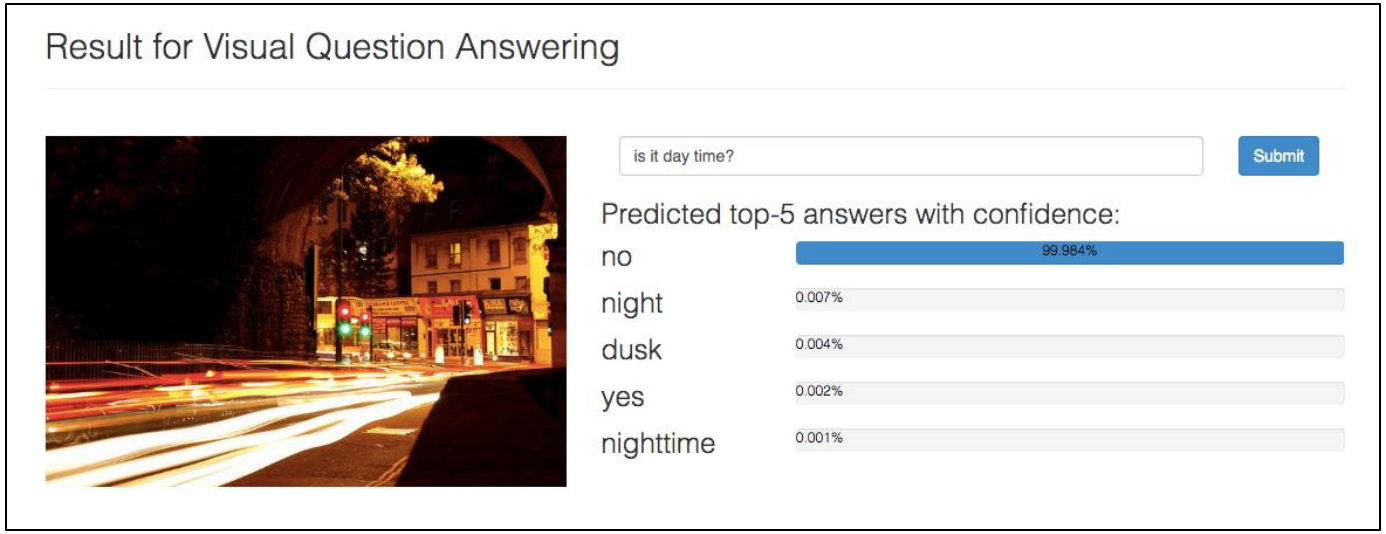

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e.g., shopping without a cashier

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e.g., track bowling ball path

e.g., calculate bat speed

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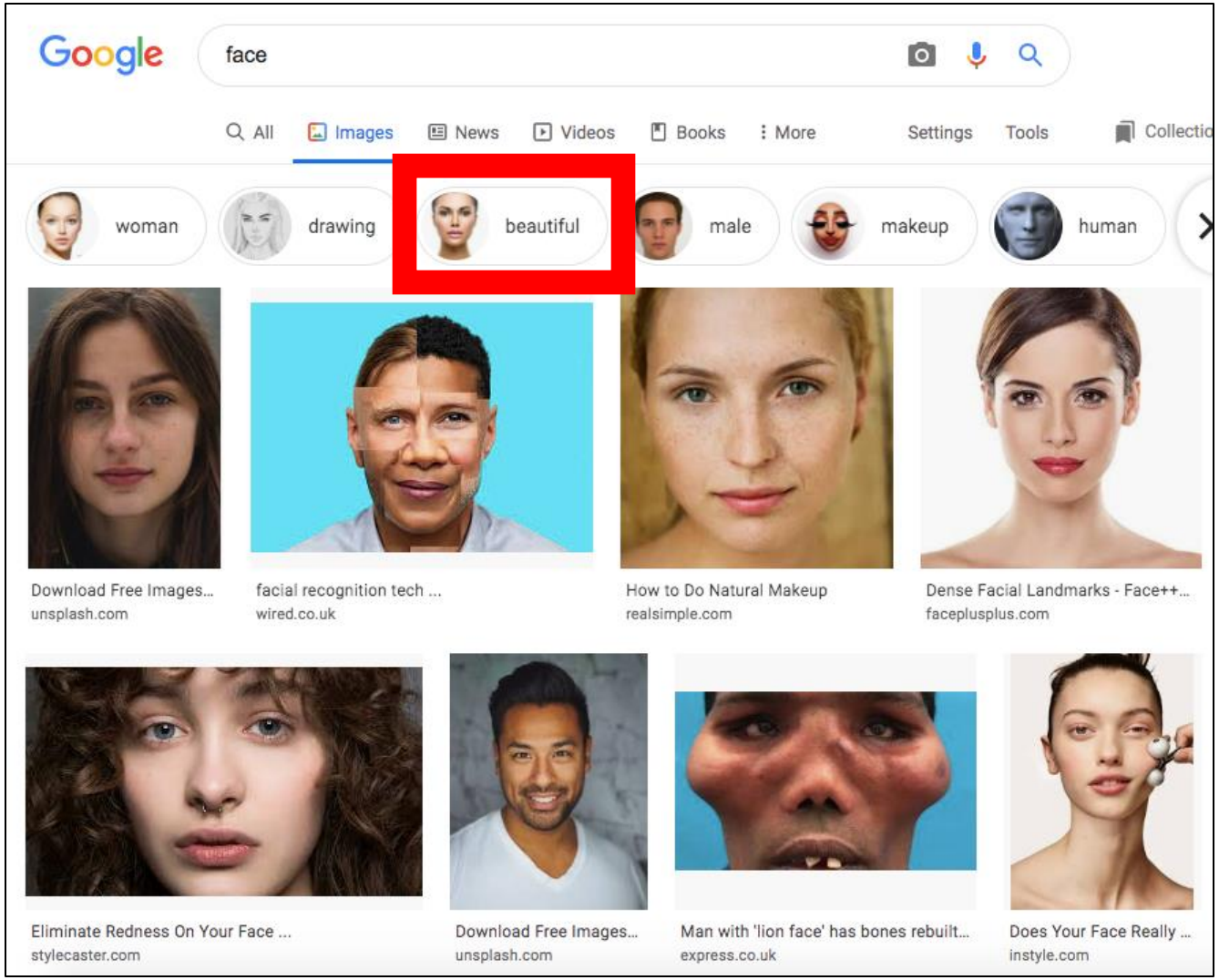

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Illumination

Object pose

Clutter

Occlusions

Intra-class appearance

Viewpoint

Slide by Kristen Grauman

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images on hard drive: 10^5
(500 GB/2 MB = 250,000)

images seen during my first 10 years: 10^9
(24 images/sec * 60 sec * 60 min * 16 hr * 365 days * 10 yrs = 5,045,760,000)

images seen by all humanity: 10^{20}
(7.5 billion humans[1] * 24 images/sec * 60 * 60 * 16 * 365 * 60 yrs = $2.23 * 10^{20}$)

[1] http://www.worldometers.info/world-population/

Adapted from slides by Antonio Torralba

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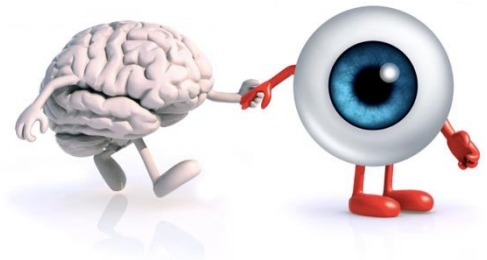
Recall: Origins of Computer Vision



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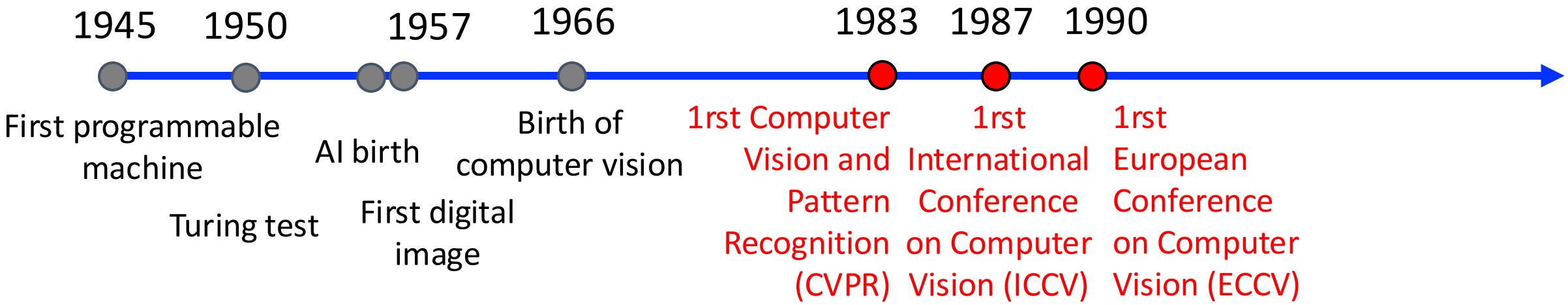
Emergence of “Official” Research Community



Variety of Research Communities/Venues

Conferences

- Recurring event, often annual
- Most prestigious publication venue
- Papers are length constrained

e.g., beyond CVPR, ICCV, and ECCV, also:

- Winter conference on Applications in Computer Vision (WACV)
- Asian Conference on Computer Vision (ACCV)
- British Machine Vision Conference (BMVC)
- Medical Image Computing and Computer-Assisted Intervention (MICCAI)
- Conference on Automatic Face and Gesture Recognition (IEEE FG)

Journals

- Periodical publication
- Next most prestigious publication venue
- Papers can be any length
- Often, longer review cycle than conferences

e.g.,

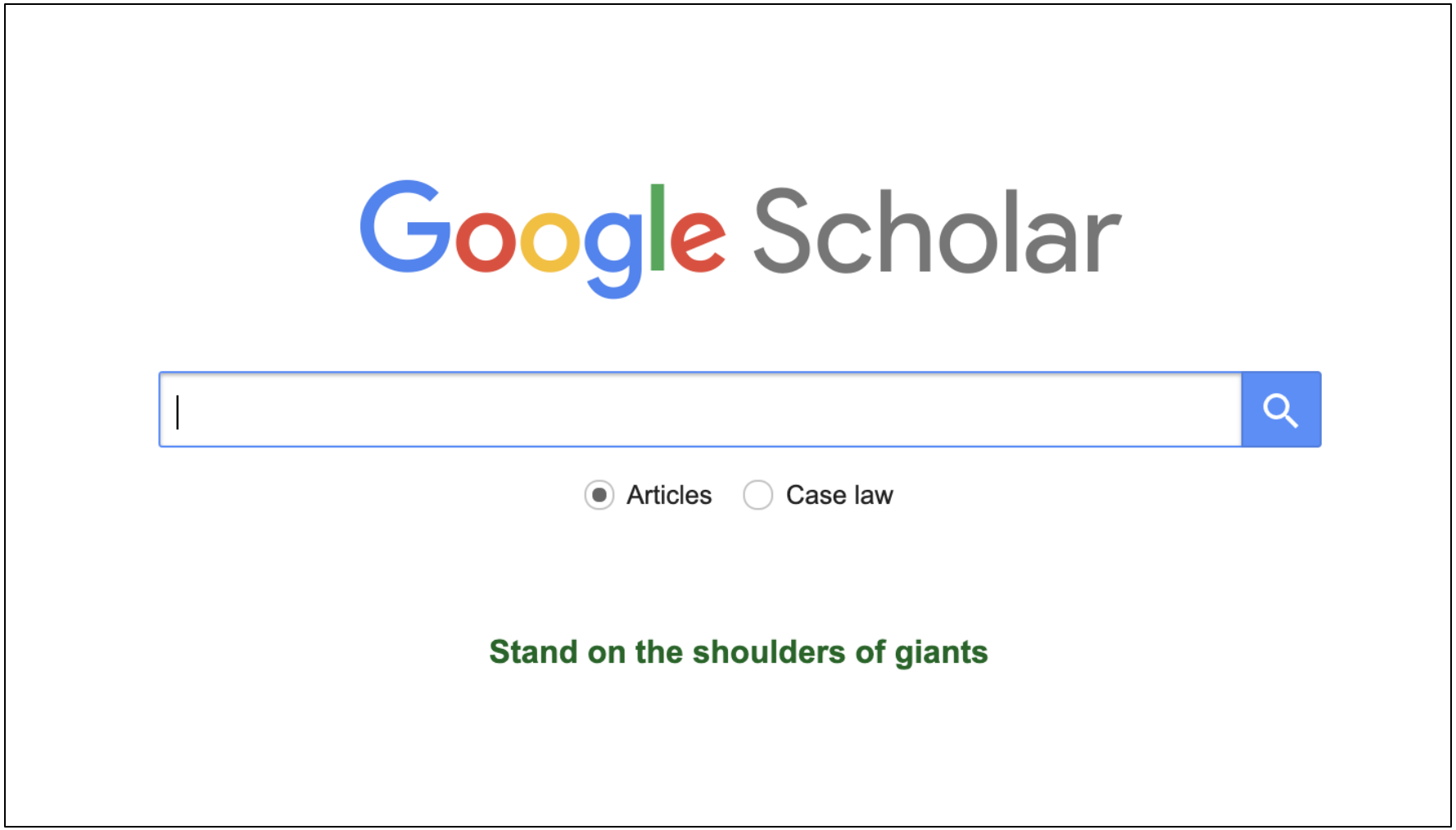
- International Journal of Computer Vision (IJCV)
- Transactions on Pattern Analysis and Machine Intelligence (PAMI)

Workshops

- Typically associated with a conference, focusing on a specialized topic (some recur and even grow into conferences)
- Least prestigious publication venue
- Often, papers are length constrained
- Shorter review cycle than conferences

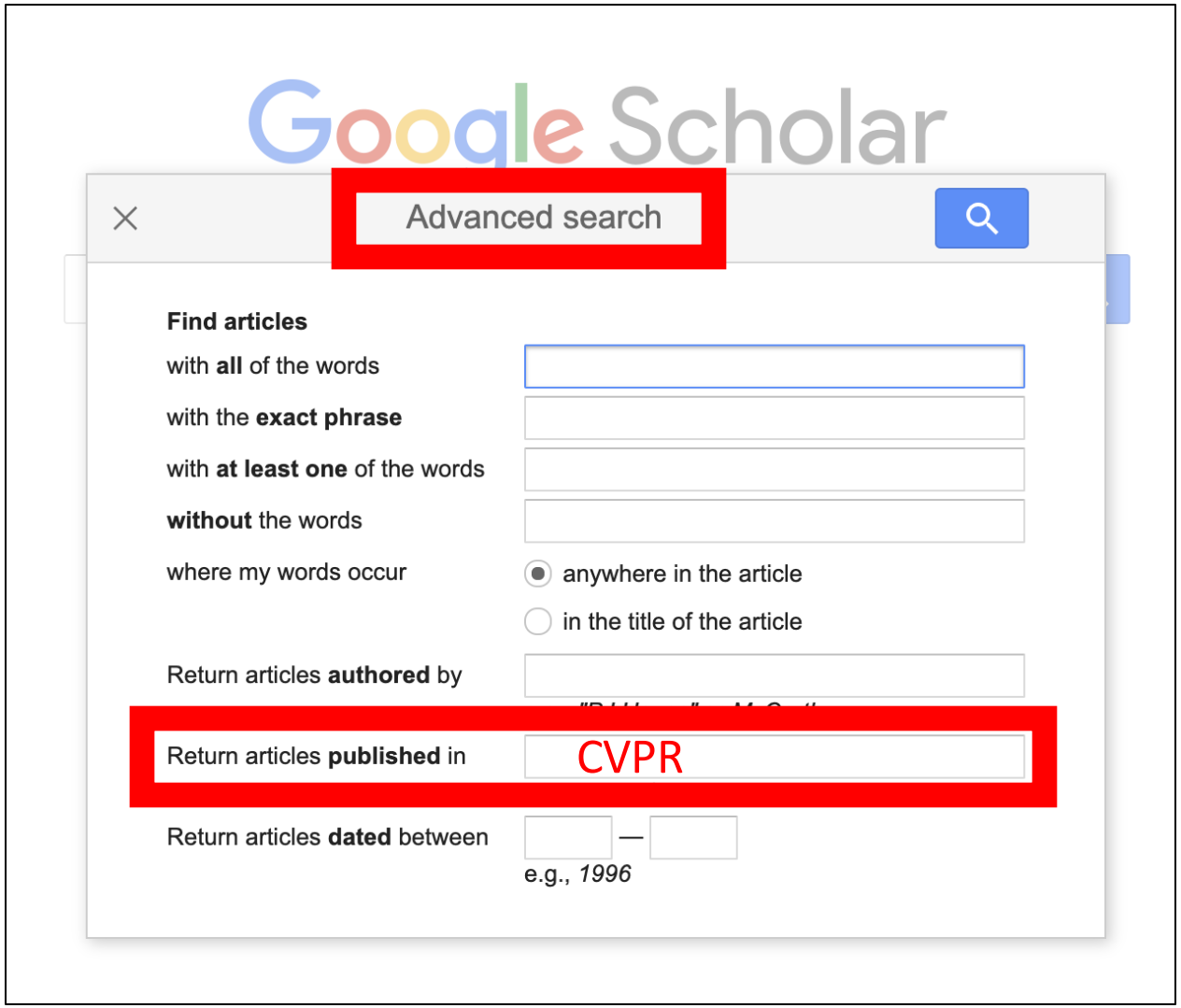
Typically, 10s associated with major conferences

Researchers' Success Metric: Publications



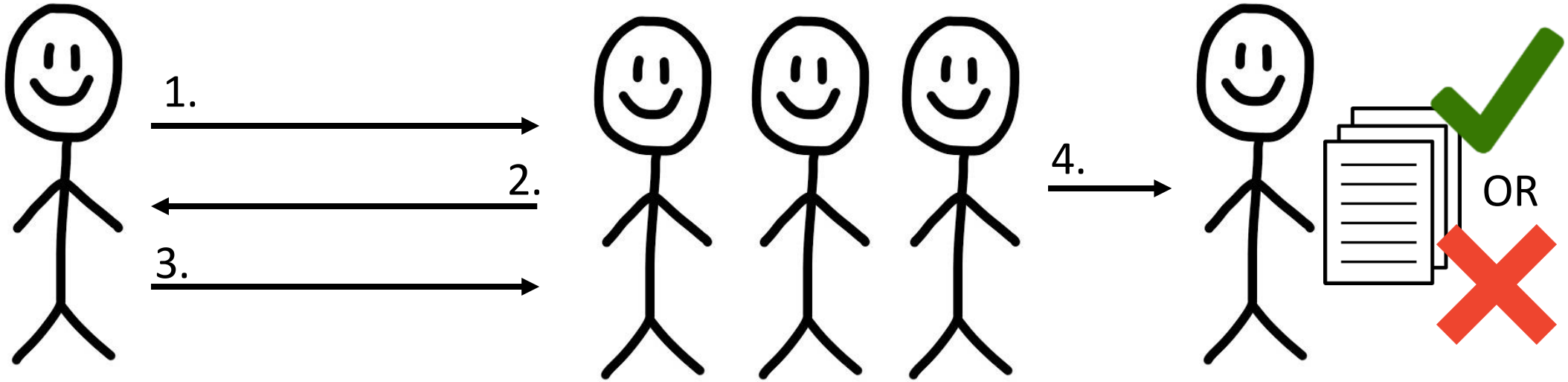
Tool to find publications

Researchers' Success Metric: Publications



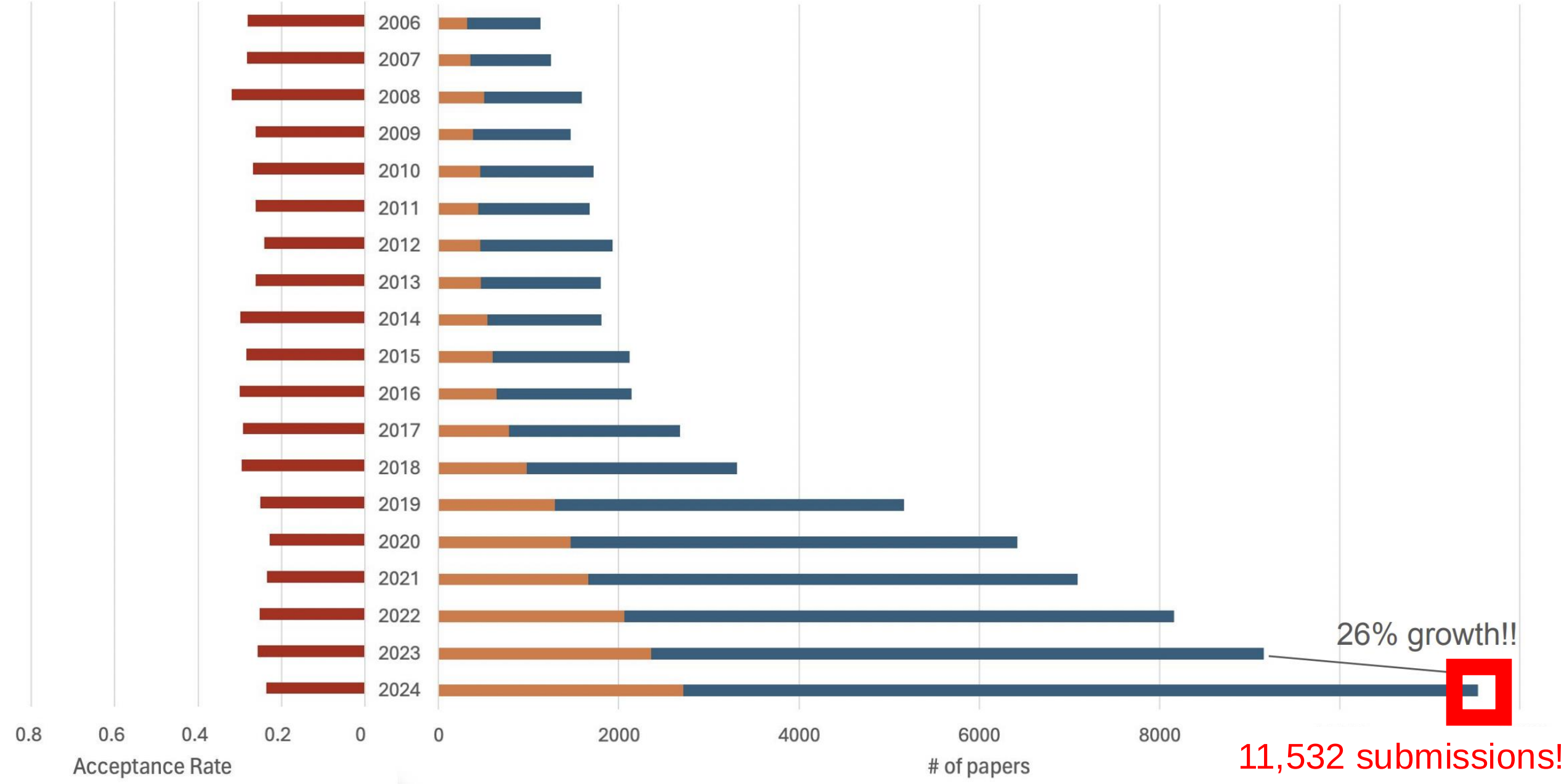
Publication Process

- Typically, 1-3 years to publish in top venues (e.g., CVPR, ICCV, ECCV)
  1. Submit paper about research you conduct
  2. ~2 months later, receive reviews from at least 3 reviewers
  3. Write short response (rebuttal) to reviewers' feedback in ~1 week
  4. Meta-reviewer makes final decision ~1 month later: accept or reject
  5. If accepted, paper is published ~4 months later



Research Community Labor; e.g., CVPR

https://cvpr.thecvf.com/media/cvpr-2024/Slides/32147.pdf



Research Community Labor; e.g., CVPR

Number of papers submitted to CVPR 2023: 11,532

Author labor estimate: ~$1.7 billion

- 11,532 submissions x 2 authors/submission x 1 year/author x $75,000/year = $1,729,800,000
    * median of 5 authors per paper (2023 statistics)

Reviewer labor estimate: ~$4.2 million

- 11,532 submissions x (3 reviewers x 3 hr/paper x $35/hr + 1 AC x 1 hr/paper x $50/hr)= $4,209,180
    * 9,872 reviewers
    * 477 area chairs

https://cvpr.thecvf.com/media/cvpr-2024/Slides/32147.pdf
https://public.tableau.com/views/CVPR2023SubjectAreasbyTeamSize/Dashboard1

Prestige of Computer Vision (Google Scholar)

Top publications

Top cited publications over the last five years Learn more

	Publication	h5-index
1.	Nature	488
2.	IEEE/CVF Conference on Computer Vision and Pattern Recognition	440
3.	The New England Journal of Medicine	434
4.	Science	409
5.	Nature Communications	375

CVPR is 2nd most impactful publication venue of all journals and conferences in all of science!

h5-index: largest number such that h articles published in 2019-2024 have at least h citations each

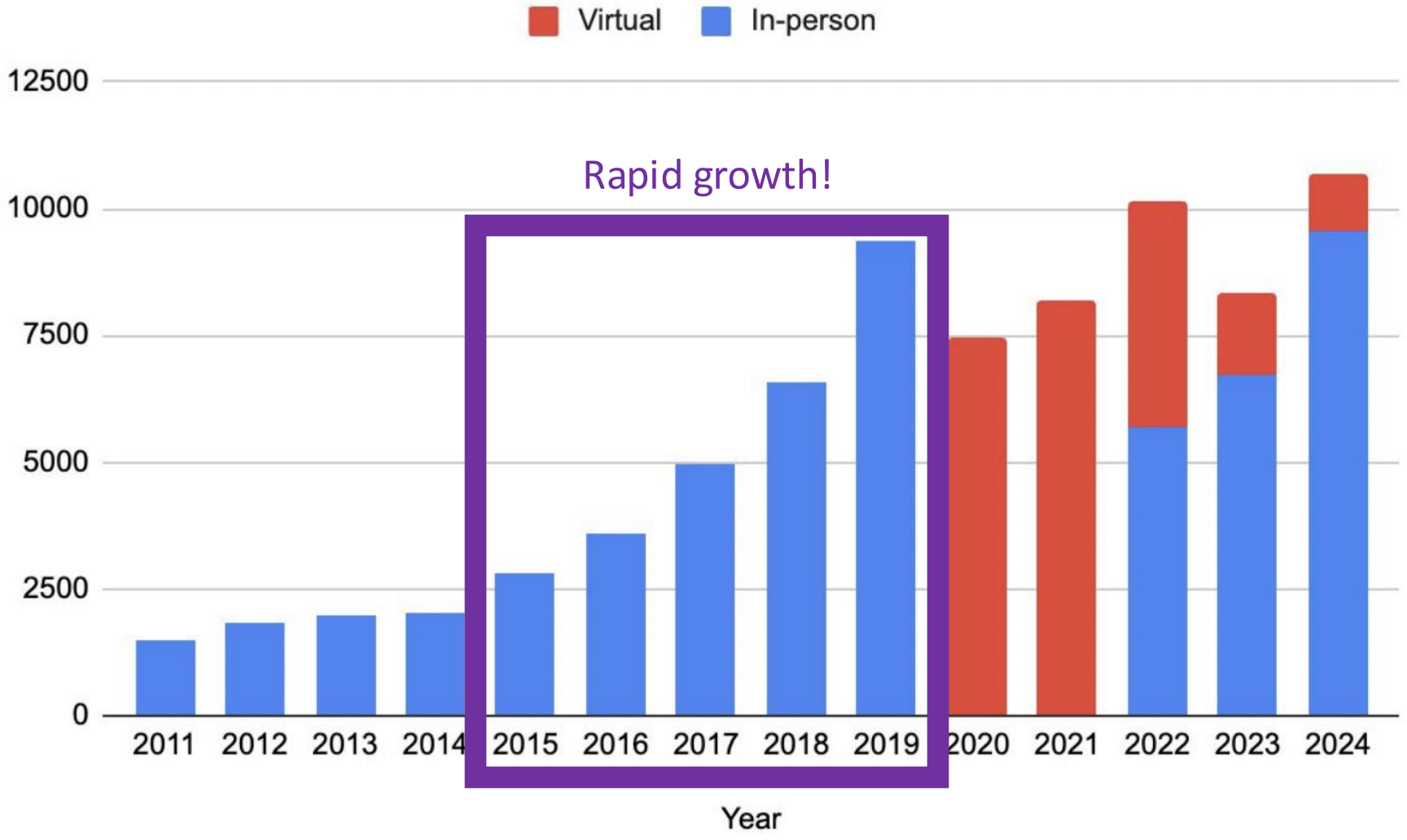
Prestige of Computer Vision (Google Scholar)

	Publication	h5-index
1.	IEEE/CVF Conference on Computer Vision and Pattern Recognition	440
2.	Neural Information Processing Systems	337
3.	Advanced Materials	327
4.	International Conference on Learning Representations	304
5.	IEEE/CVF International Conference on Computer Vision	291
6.	Journal of Cleaner Production	272
7.	International Conference on Machine Learning	268
8.	IEEE Access	266
9.	Advanced Functional Materials	244
10.	Advanced Energy Materials	234
11.	Chemical engineering journal	232
12.	ACS Nano	221
13.	AAAI Conference on Artificial Intelligence	220
14.	Meeting of the Association for Computational Linguistics (ACL)	215
15.	Energy & Environmental Science	211
16.	Applied Catalysis B: Environmental	210
17.	Renewable and Sustainable Energy Reviews	207
18.	European Conference on Computer Vision	206

Within engineering and computer science, CV venues rank high for most impactful publication venues of all journals and conferences!

Research Community Size

Number of CVPR attendees:



https://cvpr.thecvf.com/media/cvpr-2024/Slides/32147.pdf

Research Community Size

Attendees from 76 Countries/Regions!

United States 5074
Canada 352
Mexico 16
Puerto Rico 1

Brazil 27
Colombia 11
Ecuador 7
Peru 6
Argentina 4
Chile 2
Costa Rica 1
Jamaica 1

Germany 377
United Kingdom 330
Switzerland 171
France 141
Italy 118
Netherlands 64
Spain 60
Sweden 56
Belgium 34
Denmark 33
Austria 23
Czech Republic 22
Turkey 18
Norway 13
Ireland 12
Greece 11

Finland 16
Poland 15
Hungary 9
Portugal 9
Slovenia 9
Luxembourg 8
Portugal 9
Serbia 4
Croatia 3
Estonia 3
Romania 3
Albania 1
Slovakia 1

China 1511
South Korea 775
Japan 347
Singapore 171
Hong Kong 134
Israel 117
India 110
Taiwan 83
United Arab Emirates 40
Saudi Arabia 35
Viet Nam 22
Qatar 6
Thailand 6
Armenia 3
Bangladesh 3
Afghanistan 2
Iran 2
Macau 2
Kazakhstan 1
Malaysia 1
Pakistan 1

Ethiopia 69
Nigeria 9
Senegal 3
Rwanda 2
Burkina Faso 1

Burundi 1
Cameroon 1
Ghana 1
Mauritius 1

Australia 125
New Zealand 8

https://cvpr.thecvf.com/media/cvpr-2024/Slides/32147.pdf

Course Focus: What Does the Research Community Talk About and Where Is It Going?

Today's Topics

- Computer vision: origins
- What makes computer vision hard?
- Research in computer vision
- Course logistics

Course Objectives

- Understand core computer vision problems and their typical solutions:

1. Recognize and define core computer vision problems
2. Identify types of algorithms commonly used to solve each problem alongside their general properties that make them well-suited for the problem
3. Characterize strengths and weaknesses of benchmarks used to track progress on each problem (i.e., data source, data annotation process, evaluation metrics)
4. Critique modern datasets used to train algorithms
5. Experiment with modern computer vision libraries and computing resources to solve computer vision problems

Course Objectives

- Analyze and present cutting-edge research:

    1. Identify in research papers the novelty claims, mechanisms used to validate the claims (e.g., theories and experiments), and why the papers' contributions matter to society

    2. Deliver oral presentations that explain research papers

    3. Discuss the merits and limitations of research papers

Course Objectives

- Conduct and communicate about a novel project:

    1. Design and execute a project involving computer vision, such as comparing and contrasting existing works, evaluating existing work in novel settings, or creating novel methods
    2. Create and deliver an oral presentation about the project
    3. Describe the project through a final report
    4. Review fellow students' presented projects and provide constructive feedback

Course Topics: Tentative Schedule

Week	Topic(s)
1	Introduction
2	Rise of Neural Networks
3	Object Recognition
4	Image Classification, Semantic Segmentation
5	Object Detection, Instance Segmentation
6	Object Tracking, Vision and Language
7	Foundation Models, Image Synthesis

Background

Week	Topic(s)

8-13: student-led presentations

14	Efficient and Responsible Computer Vision
15	Responsible Computer Vision

Course Resources

- Website with Syllabus:
  - https://dannagurari.colorado.edu/course/recent-advances-in-computer-vision-fall-2024/
- Lecture Slides: hyperlinked from course website
- Lecture Recordings: will be available on Canvas

Q&A: “How does this course differ from other courses?”

- Unique benefits:
  - Pursuing ***industry*** position? – learn how to identify what is possible from cutting edge research and incorporate the latest methods into technology
  - Pursuing ***research*** position? – learn how to identify gaps in research and publish/present novel work that fill those gaps

- Other related courses (e.g., “neural networks and deep learning” and “computer vision”)
  - Lack training on how to engage with modern research
  - Focus only on the fundamentals rather than the bleeding edge

Q&A: “Do I have the appropriate pre-requisites/background?”

- Familiarity with machine learning required, and ideally with neural networks

Note: It is common to feel an “imposter syndrome” in this course, as research papers are incredibly dense with many unexplained details. If you feel this, know that you are likely in good company!

Q&A: “What are the assignments?”

- Reading assignments most weeks (first assignment due next week)
- Final project on a topic of your choice
- Lecture about a computer vision topic (only graduate students)
- Late policy
  - Penalized 1% of grade per hour for up to 2 hours
  - No credit if more than 2 hours late

- *Collaboration policy: working with other students and AI is permitted, but the work you submit must be your own.*

Reading Assignment

- We will cover 3 types of research papers:
  - Datasets
  - Algorithms
  - Surveys

Final Project

- Process (described in syllabus and on course website):
  - **5th week** (10%): submit proposal about a self-chosen topic
  - **7th week** (20%): submit outline of proposed project
  - **Last week of semester** (20%): present project with a poster
  - **Last Lecture** (10%): evaluate peers' final projects
  - **Finals week** (40%): submit final project report

Student-Led Lectures (Only for Grad Students)

- Process (described in syllabus and on course website):
  - **4th week**: assigned topic with partner
  - **2+ weeks prior to lecture** (10%): schedule meeting with me to review 4-6 recent publications at a premiere computer vision conference (e.g., CVPR, ICCV,ECCV) that you will share 48+ hours beforehand; we will assign 1 as required reading and 1 as optional reading
  - **At least 1 week prior to first lecture** (40%): schedule meeting with me to review a completed draft of the lecture slides that you will share 24+ hours before this meeting
  - **Lecture** (50%): ~50-minute presentation followed by ~25-minute discussion facilitated by instructor based on student-submitted discussion points
  - **Partner work distribution**: divide and conquer or do everything together; up to you!

Q&A: “How is my final grade determined?”

	% of Final Class Grade
Class Participation	10%
Reading Assignments	45%
Final Project	45%

	% of Final Class Grade
Class Participation	10%
Reading Assignments	30%
Student-Led Lecture	30%
Final Project	30%

* 2 unexcused absences permitted with no impact to your final grade

Q&A: “What are required textbooks?”

- None. Links to required readings will be posted on the course website for each class meeting.

Q&A: “How Do I Get Answers to my Questions?”

- **Questions for Instructor**: I will stay after each class lecture to answer questions.
- **Office Hours**: The course manager will host office hours every Tuesday 2-3pm.
- **Appointments**: Email us. Typically, ~24 hours to respond.
- **Regrade requests**: All requests must be emailed to the instructor within 2 weeks of receiving the grade to be considered.

Introductions

Instructor: Danna Gurari; aka, Dr. G; preferred pronouns: she/her:

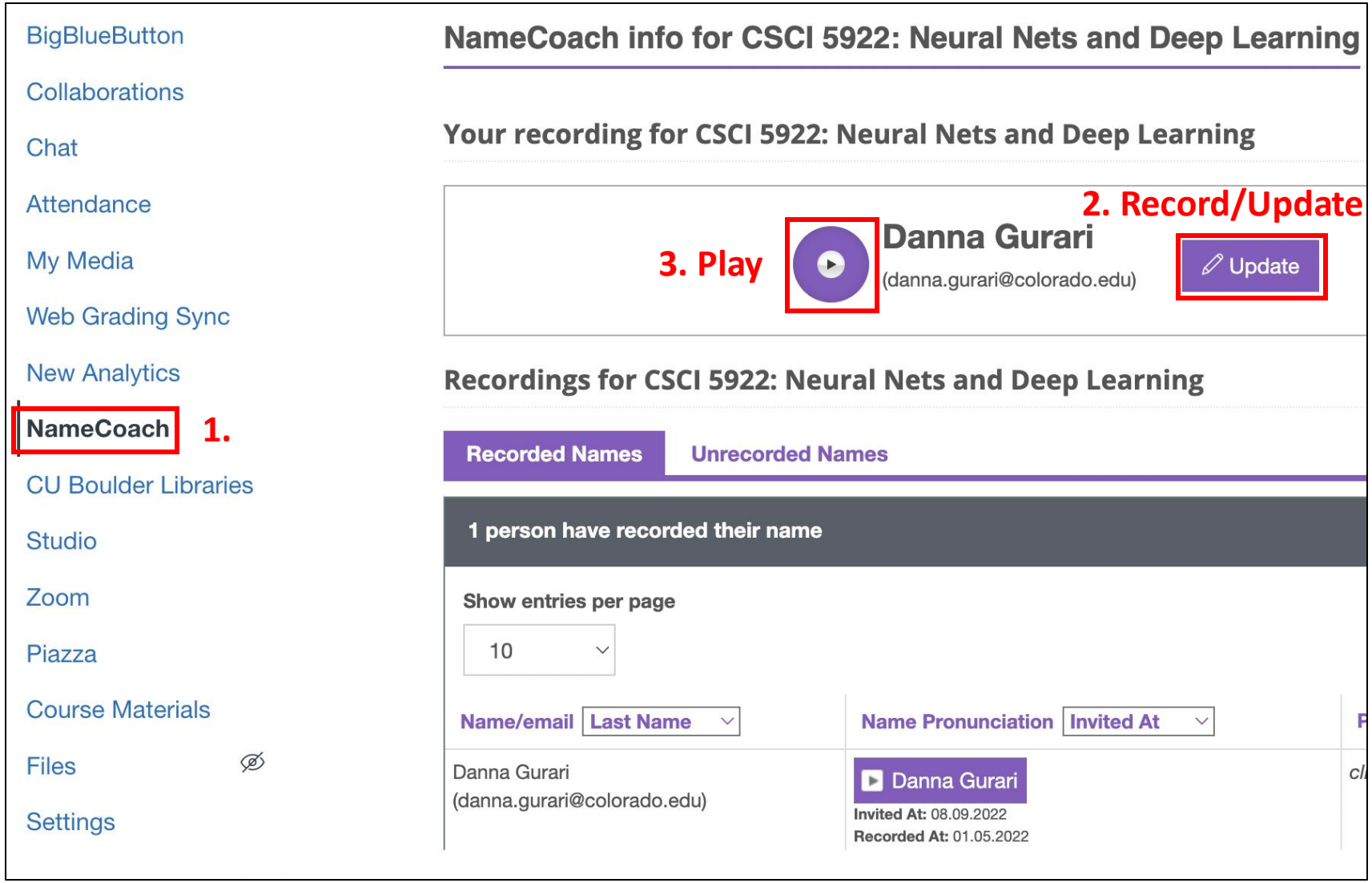
Course manager: Josh Myers-Dean; preferred pronouns: he/him:

Introductions

NameCoach: share your name pronunciation

To record your name:

1. Find NameCoach in Canvas courses page
2. Click on record button to start
3. Review recording by clicking on play button



My Experience Relating to Computer Vision

2004-2005

Masters student designing system to record ultrasound images

2005-2007

Software engineer helping to record satellite images

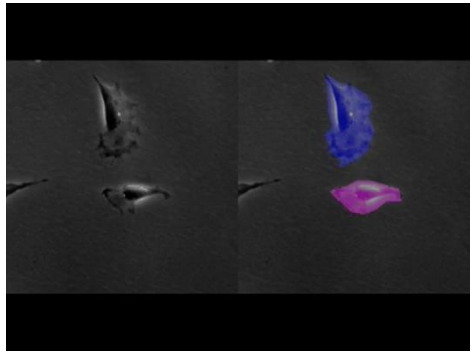
2007-2010

Software developer and project manager helping to record visible and infrared video

Source: Boulder Imaging

2010-2015

PhD student designing methods to segment and track cells in images and videos



2015-Present

Postdoctoral fellow and then assistant professor overseeing research projects related to many computer vision problems

e.g., image classification, object detection, semantic segmentation, object tracking, image captioning, visual question answering, style transfer, image inpainting, and image search

My Experience Relating to Computer Vision

2004-2005 | 2005-2007 | 2007-2010 | 2010-2015 | 2015-Present

Masters student designing system to record ultrasound images

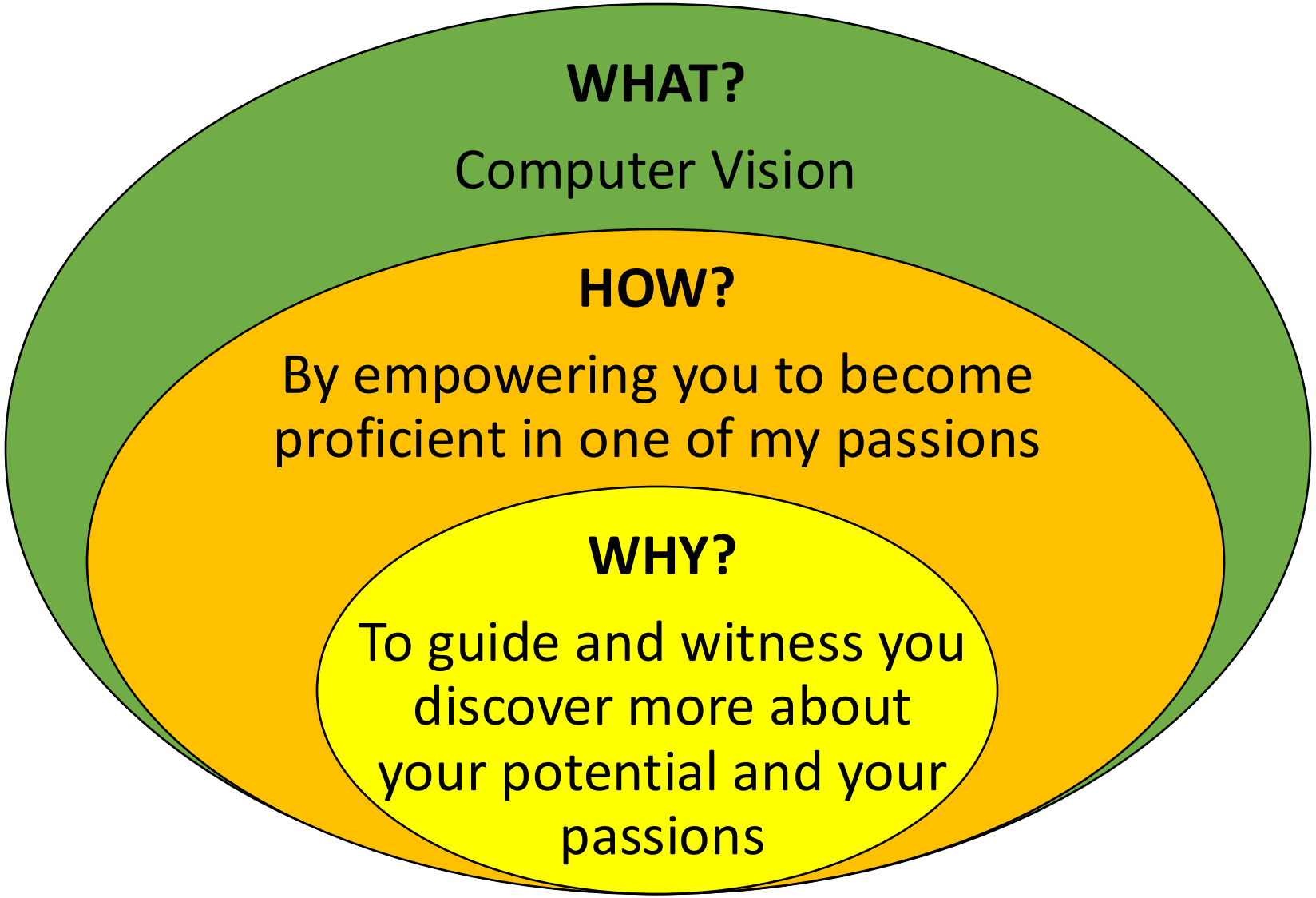
Software engineer helping to record satellite images

Software developer and project manager helping to record visib and infrared video

Source: Boulder Imaging

62 publications, most involving computer vision

What is My “Why” for Teaching You…



Google Form: Please Share…

- Your goals and interests
- Any topics you want covered for the student-led lectures

Today's Topics

- Computer vision: origins
- What makes computer vision hard?
- Research in computer vision
- Course logistics


The End