Deep Learning for Computer Vision

History

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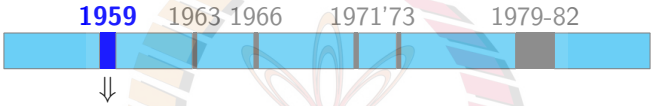
Outline

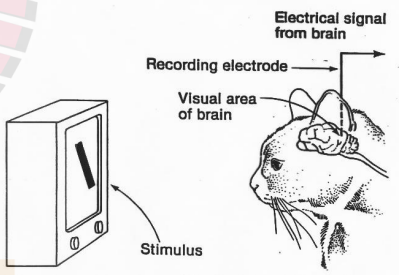
Disclaimer

- A history of the field as captured from multiple sources (including Szeliski's book and other sources credited on each page)
- A slightly biased history, as relevant to the topics we cover in this course. There is more to history in related topics (e.g. geometry-based vision, physics-based vision, image/video processing and compression, graphics, computational photography) not covered herein.
- A slight predisposition to work based on images, more than videos.

Early History[1]



- David Hubel and Torsten Wiesel publish their work *"Receptive fields of single neurons in the cat's striate cortex"*
- Placed electrodes into primary visual cortex area of an anesthetized cat's brain
- Showed that simple and complex neurons exist, and that visual processing starts with simple structures such as oriented edges



[1] Credit: Rostyslav Demush, medium.com

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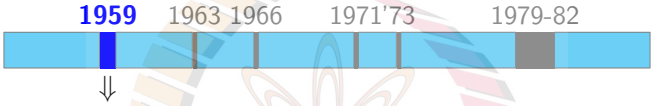

- World's first digital image: Russell Kirsch and his colleagues develop an apparatus to transform images into number grids
- Image of Russell's infant son: grainy 5cm by 5cm photo, 30,976 pixels (176×176 array)
- Now stored in Portland Art Museum

[2] Credit: Rostyslav Demush, medium.com

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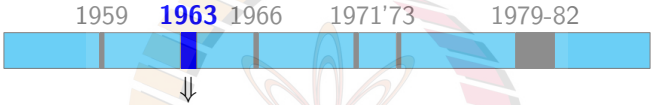

- Lawrence Roberts' PhD thesis: *"Machine Perception Of Three-Dimensional Solids"*
- Discussed extracting 3D information about solid objects from 2D photographs of line drawings
- Discussed issues such as camera transformations, perspective effects, and the rules and assumptions of depth perception

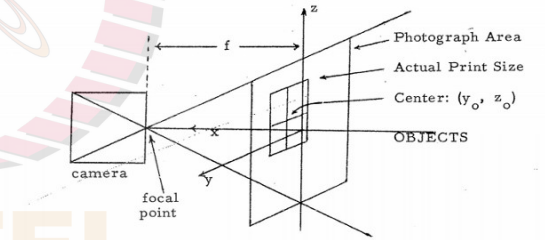

Figure 1: Camera Transformation

[3] Credit: Rostyslav Demush, medium.com

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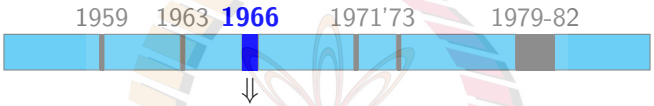
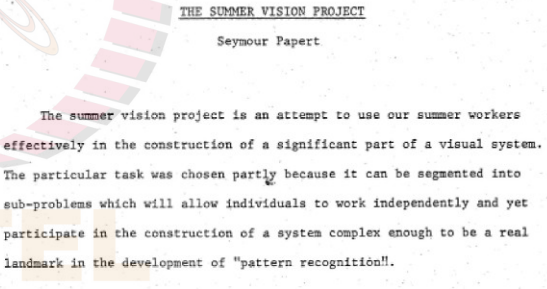


- Seymour Papert (with Gerald Sussman) from MIT launched the *Summer Vision Project*
- Aimed to develop a platform to automatically segment background/foreground and extract non-overlapping objects from real-world images



THE SUMMER VISION PROJECT

Seymour Papert

The summer vision project is an attempt to use our summer workers effectively in the construction of a significant part of a visual system. The particular task was chosen partly because it can be segmented into sub-problems which will allow individuals to work independently and yet participate in the construction of a system complex enough to be a real landmark in the development of "pattern recognition".

[4] Credit: Rostyslav Demush, medium.com

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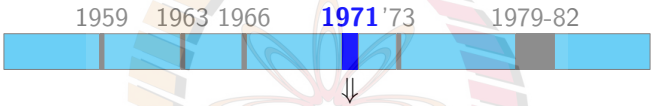
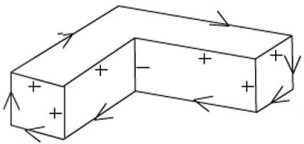


- Discern a shape in a line drawing by labeling lines as convex, concave, and occluded
  - David Huffman et al, *Impossible objects as nonsense sentences*, Machine Intelligence, 8:475-492, 1971
  - Max Clowes et al, *On seeing things*, Artificial Intelligence, 2:79-116, 1971



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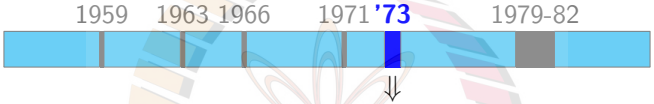
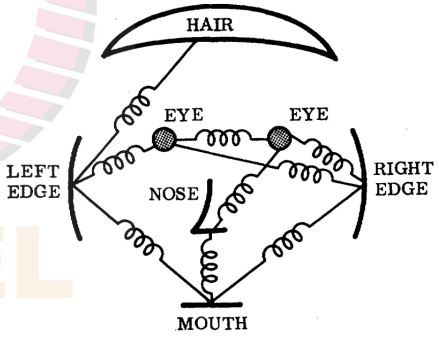


- *Pictorial Structures* model by Fischler and Elschlager
- Given a visual object's description, find the object in a photograph
- Part of the solution is specification of a descriptive scheme, and a metric on which to base the decision of "goodness" of matching or detection



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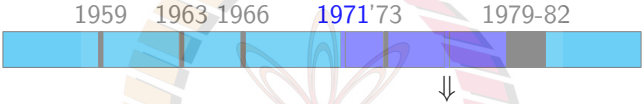
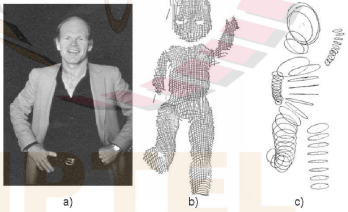
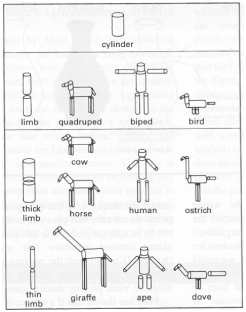


- Object recognition through shape understanding
  - Binford 1971, Generalized Cylinders
  - Marr and Nishihara 1978, Skeletons and Cylinders
- MIT's Artificial Intelligence Lab offers a "Machine Vision" course





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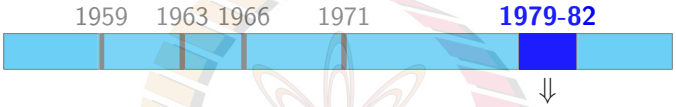
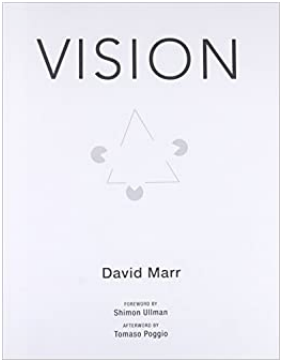


- David Marr, *Vision: A computational investigation into the human representation and processing of visual information*, 1982
- Established that vision is hierarchical
- Introduced a framework where low-level algorithms that detect edges, curves, corners, etc., are used to get high-level understanding of visual data



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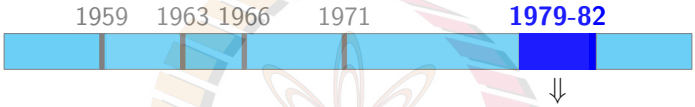
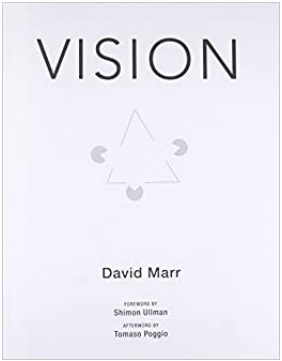


Marr's Representational Framework

- A primal sketch of an image, where edges, bars, boundaries etc., are represented
- A $2\frac{1}{2}$-D sketch representation where surfaces, information about depth, and discontinuities on an image are pieced together
- A 3D model that is hierarchically organized in terms of surface and volumetric primitives



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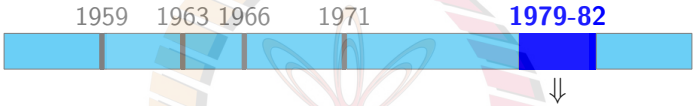
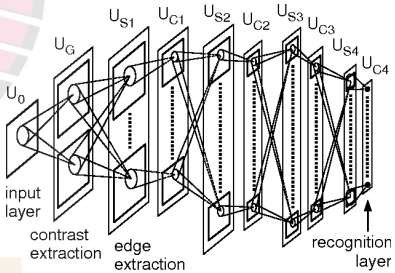


- Kunihiko Fukushima' *Neocognitron*, a self-organizing artificial network of simple and complex cells to recognize patterns, unaffected by position shifts
- The original ConvNet!
- Included convolutional layers with weight vectors (known as filters)



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Outline

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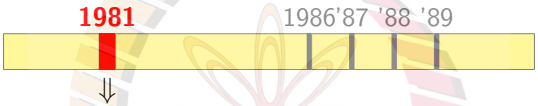
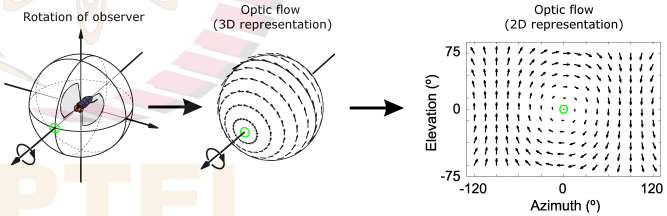


- **Optical Flow:** Horn and Schunck develop method to estimate the direction and speed of a moving object across two images
- Flow is formulated as a global energy functional which is minimized



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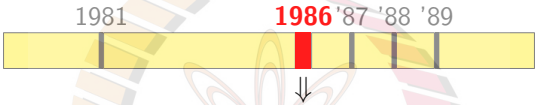
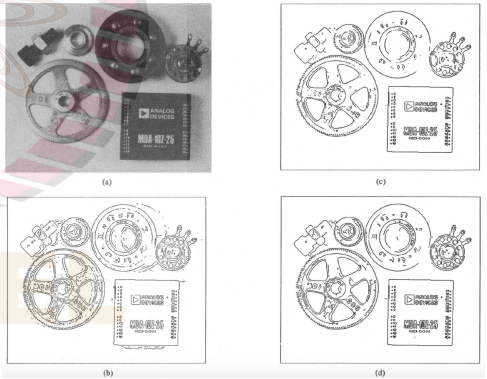


- **Canny Edge Detector:** Multi-stage edge detection operator, with a computational theory of edge detection
- Used calculus of variations to find the function that optimizes a given functional
- Well-defined method, simple to implement, became very popular for edge detection



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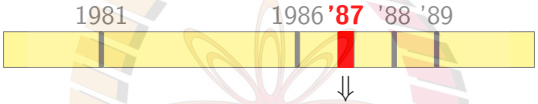
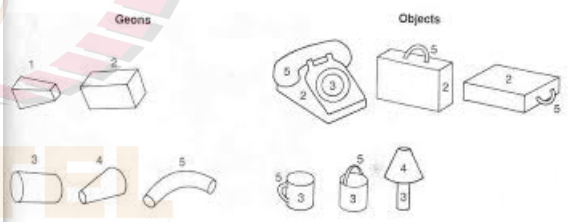


- **Recognition by Components Theory:** Proposed by Biederman
- Bottom-up process to explain object recognition
- Object's component parts: *geons*, based on basic 3-dimensional shapes (cylinders, cones, etc.) assembled to form the object



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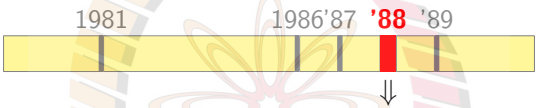
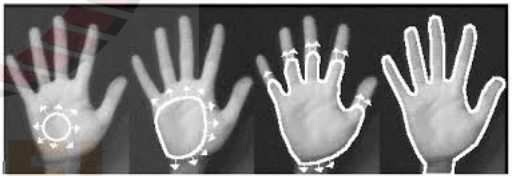


- **Snakes** or **active contour models** delineate an object outline from a possibly noisy 2D image
- Widely used in applications like object tracking, shape recognition, segmentation, edge detection and stereo matching



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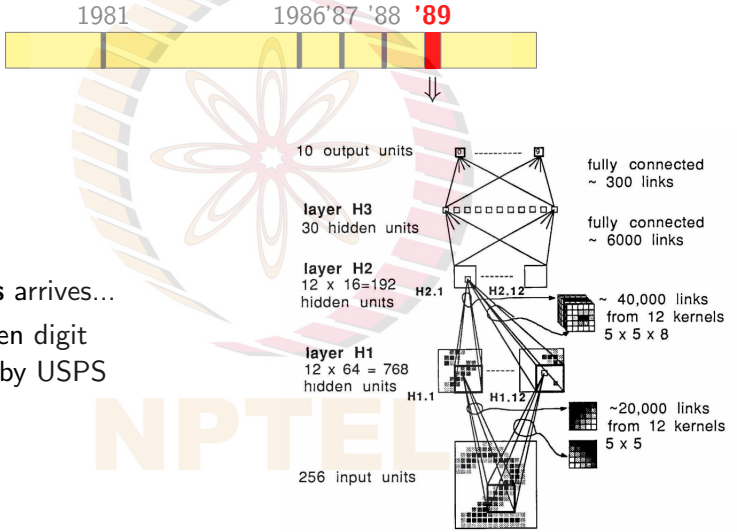

- **Backprop for CNNs** arrives...
- Applied to handwritten digit recognition provided by USPS

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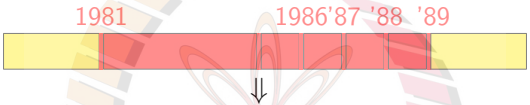

- Image Pyramids[9]
- Scale-space Processing[10]
- Wavelets[11]

- Shape-from-X[12]
- Variational Optimization methods[13]
- Markov Random Fields[14]

[9] Burt and Adelson, 1983
[10] Witkin, 1984
[11] Mallat, 1989
[12] Pentland, 1984; Blake et al, 1985
[13] Poggio et al, 1985
[14] Geman and Geman, 1985

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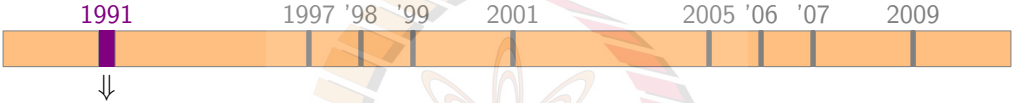

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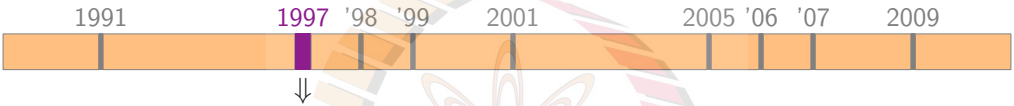

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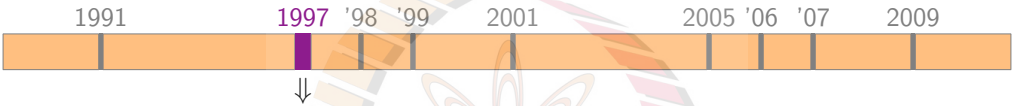

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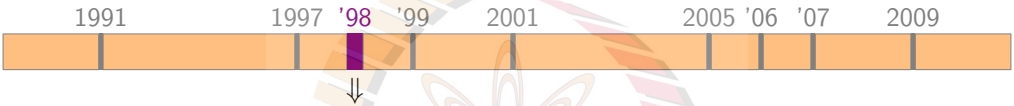

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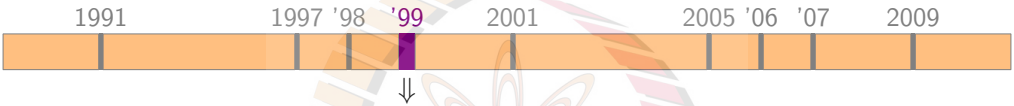

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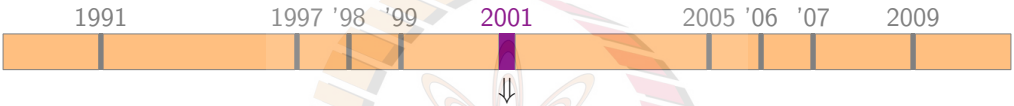

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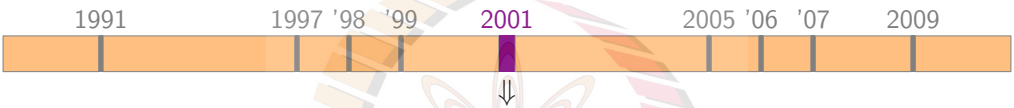

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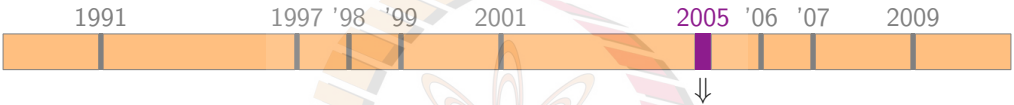

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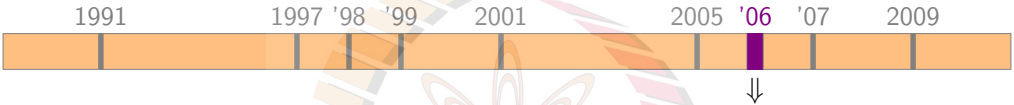

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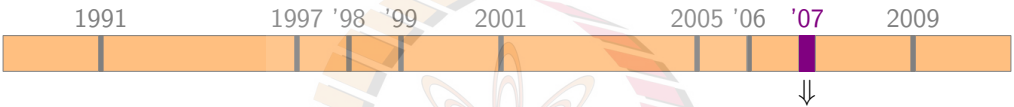

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- **Constellation models** (Fergus, Perona & Zisserman, 2007)

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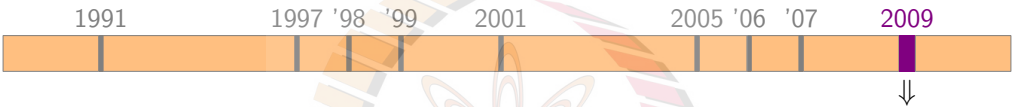

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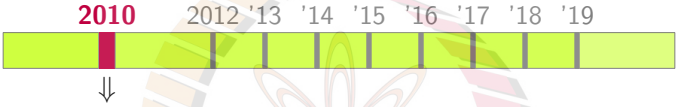
- **Particle filters**, **Mean shift** for tracking (Liu & Chen, 1998)(Cheng, 1998)
- **SIFT** (Lowe, 1999) (Lowe, 2004)
- **Viola-Jones face detection** (Viola & Jones, 2001)
- **Conditional Random Fields** (Lafferty et al, 2001)
- **Pictorial structures** revisited (Felzenszwalb & Huttenlocher, 2005)
- **PASCAL VOC** arrives; Scene/panorama/location recognition methods grow
- **Constellation models** (Fergus, Perona & Zisserman, 2007)
- **Deformable part models** (Felzenszwalb et al, 2009)

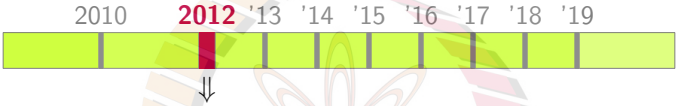
Outline

The Deep Learning Era



- ImageNet arrives

The Deep Learning Era



- ImageNet arrives
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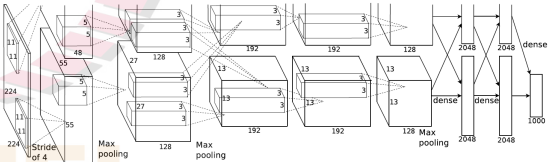
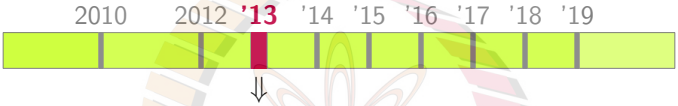


The Deep Learning Era



- ImageNet arrives
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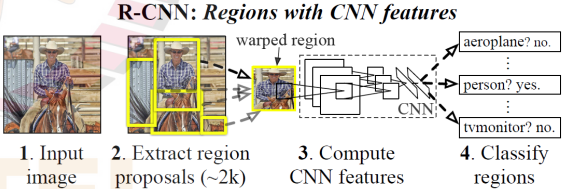

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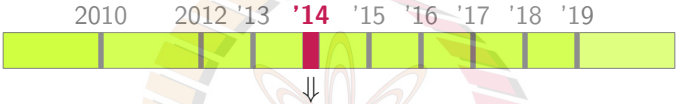

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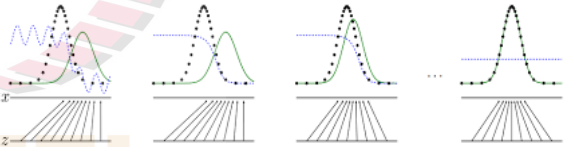

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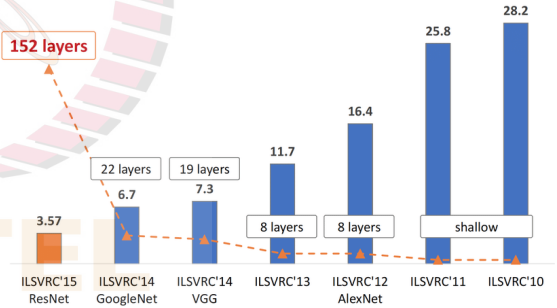

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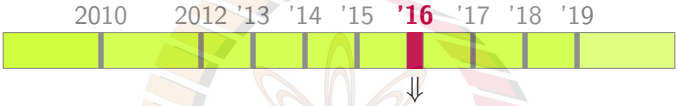

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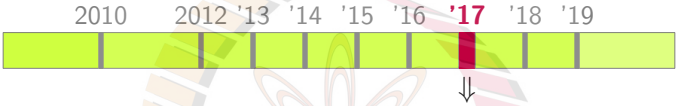

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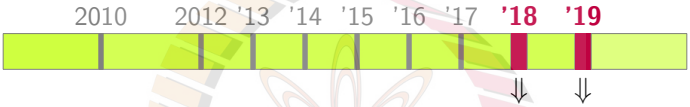

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- Scene graph generation models
- VCR dataset, Panoptic segmentation
- ...

History of Applications[15]

- **1970s:** Optical Character Recognition (OCR)
- **1980s:** Machine vision, Smart cameras
- **1990s:** Machine vision in manufacturing environments, Biometrics, Medical imaging, Recording devices, Video surveillance
- **2000s:** More biometrics, Better medical imaging, Object/Face detection, Autonomous navigation, Google Goggles, Vision on social media
- **2010s:** Everywhere around us

[15] See https://www.phase1vision.com/resources/timeline for a longer historical timeline

Homework

Readings

- Chapter 1, Szeliski, *Computer Vision: Algorithms and Applications* (Sections 1.1 and 1.2, in particular)
- Other links provided on respective slides, especially
  - Rostyslav Demush, A Brief History of Computer Vision (and Convolutional Neural Networks)

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