Human Skeletal Tracking, and the Development of KINECT

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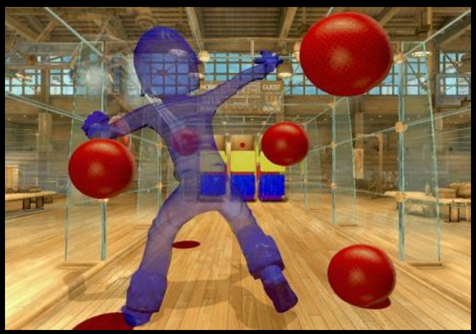
Microsoft Research

KINECT™

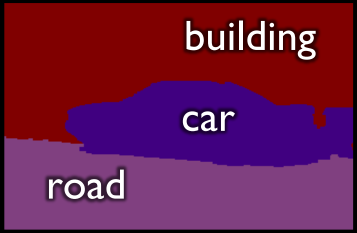
- Plugs into your Xbox or PC
- Combines new technologies:
  - depth sensing camera
  - real time human skeletal tracking
  - face and voice recognition
- Applications in both gaming and much more



Kinect: Human Motion Tracking

Talk roadmap

- Background: visual recognition



- “Project Natal”:
  a call to action

- Machine learning for
  body part recognition

- Other applications

Visual object recognition

=

0.2, 0.1, 0.1	0.1, 0.1, 0.4	0.0, 0.2, 0.7	0.1, 0.4, 0.3	1.0, 0.3, 0.3
0.2, 0.9, 0.4	0.9, 0.8, 0.7	0.3, 0.2, 0.1	0.5, 0.0, 0.2	0.5, 0.5, 0.0
0.1, 0.3, 0.5	0.3, 0.6, 0.1	0.1, 1.0, 0.5	0.9, 0.8, 0.7	0.2, 0.6, 0.7
0.3, 0.7, 0.3	0.2, 0.9, 0.5	0.1, 0.5, 0.0	1.0, 0.0, 0.9	0.1, 0.8, 0.8
0.1, 0.2, 0.7	0.6, 0.7, 0.0	0.7, 0.7, 0.9	0.2, 0.1, 0.0	0.8, 0.4, 0.5
0.6, 0.4, 0.2	0.0, 0.7, 0.2	1.0, 0.1, 1.0	0.0, 0.6, 1.0	0.3, 0.1, 0.4
0.9, 0.0, 0.0	0.7, 0.8, 0.7	0.5, 0.6, 0.6	0.6, 0.6, 0.3	0.3, 1.0, 1.0
0.9, 0.4, 1.0	0.5, 0.0, 0.7	0.6, 0.0, 0.0	0.8, 0.9, 0.2	0.4, 0.9, 0.0
0.0, 0.3, 0.5	0.2, 0.4, 0.0	0.2, 0.3, 0.1	0.5, 0.9, 0.5	1.0, 0.6, 0.6
0.9, 0.8, 1.0	0.8, 0.7, 0.5	0.2, 0.8, 0.4	0.6, 0.9, 0.8	0.9, 0.8, 0.9
0.5, 0.9, 0.7	1.0, 0.1, 0.0	0.5, 0.6, 0.7	0.4, 0.5, 0.8	0.4, 0.8, 0.7
0.7, 0.6, 0.6	0.6, 0.2, 0.1	0.4, 0.7, 0.3	0.1, 0.2, 0.4	0.9, 1.0, 0.2
0.3, 0.3, 0.1	1.0, 0.3, 0.1	0.6, 0.4, 0.9	0.3, 0.7, 0.2	0.8, 0.1, 0.0
0.1, 0.4, 1.0	0.9, 0.9, 0.2	1.0, 0.4, 0.4	1.0, 1.0, 0.5	0.4, 0.8, 0.5
0.0, 0.7, 0.6	0.6, 0.1, 0.9	0.0, 1.0, 0.8	0.2, 0.7, 0.8	0.7, 0.0, 0.2
0.3, 0.0, 0.4	0.9, 0.7, 0.5	0.0, 0.1, 1.0	0.6, 0.2, 0.4	0.6, 0.4, 0.6
0.0, 0.2, 0.4	1.0, 0.9, 0.3	0.8, 0.2, 0.3	1.0, 0.0, 0.6	0.2, 0.1, 0.1
0.4, 0.6, 0.0	0.7, 0.8, 0.8	0.5, 0.7, 0.5	0.7, 0.4, 0.5	0.2, 0.3, 0.4
0.5, 0.1, 0.1	1.0, 0.9, 0.4	0.6, 0.6, 0.3	0.5, 1.0, 0.6	0.8, 0.9, 0.1
0.0, 0.5, 0.3	0.4, 0.5, 0.1	0.6, 0.1, 0.2	0.5, 0.6, 0.7	1.0, 0.9, 0.5
1.0, 0.1, 0.5	0.4, 0.1, 0.6	1.0, 0.4, 0.4	0.9, 0.3, 0.5	0.6, 0.8, 0.0
0.7, 0.9, 0.3	0.6, 0.5, 0.0	0.3, 0.9, 0.6	0.3, 0.6, 0.7	0.0, 0.0, 0.5
1.0, 0.8, 0.1	0.0, 0.3, 0.0	0.4, 1.0, 0.3	0.7, 0.3, 1.0	0.4, 0.6, 1.0
0.1, 0.5, 0.3	0.8, 0.1, 0.1	0.5, 0.1, 0.2	0.1, 0.4, 1.0	0.6, 0.4, 0.7
0.3, 0.2, 0.3	0.9, 0.9, 0.4	0.7, 0.8, 0.1	0.6, 0.8, 0.0	0.4, 0.0, 0.2
0.1, 0.3, 0.0	0.2, 0.7, 0.9	0.8, 0.4, 0.8	0.0, 0.1, 0.0	0.6, 0.7, 0.8
0.7, 0.5, 0.3	0.0, 0.2, 0.6	0.5, 0.5, 0.2	0.3, 0.9, 1.0	0.8, 0.2, 0.7
1.0, 0.6, 0.8	0.5, 0.5, 0.0	0.8, 0.4, 1.0	0.1, 0.4, 0.8	1.0, 0.2, 0.9
0.1, 0.5, 0.7	0.2, 0.0, 0.6	0.3, 0.6, 0.8	0.8, 1.0, 0.1	0.5, 0.0, 0.5
1.0, 0.5, 0.4	0.3, 0.2, 1.0	0.4, 0.0, 0.5	0.8, 0.9, 0.7	0.5, 0.1, 0.7

viewing angle

object pose

lighting

occlusion

scale

environment

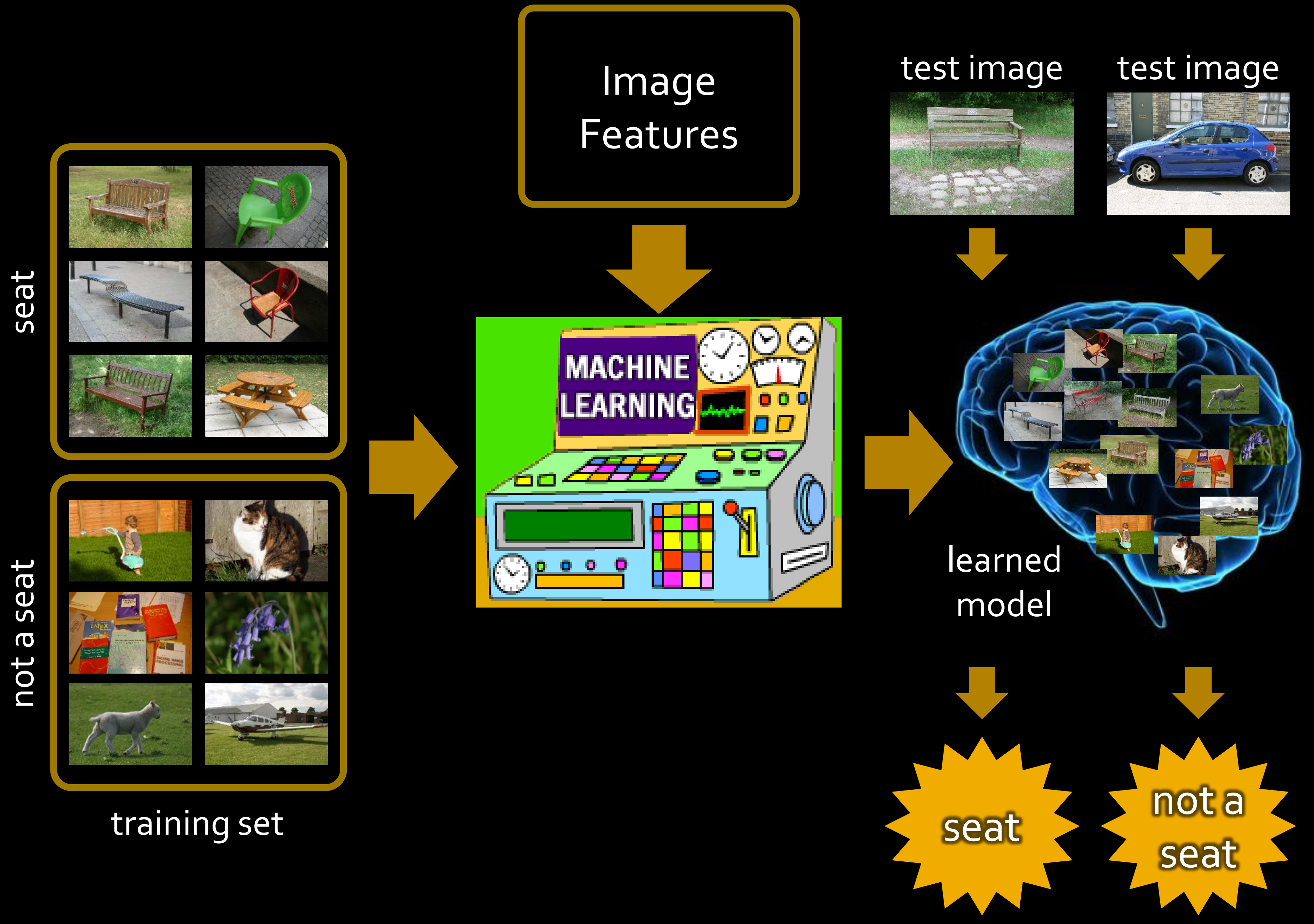
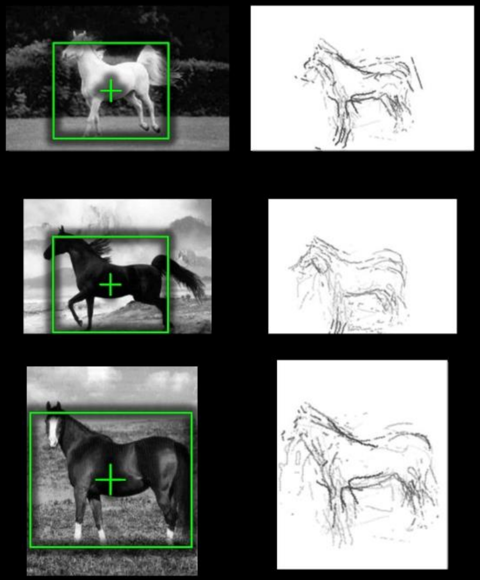
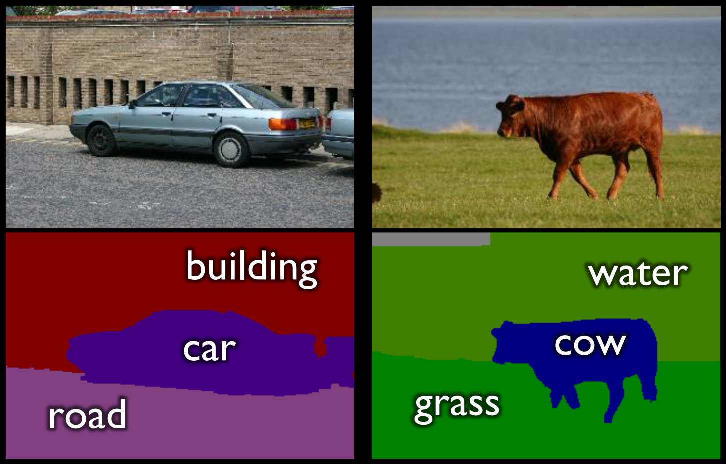


Image Features
test image
test image
seat
not a seat
training set
MACHINE LEARNING
learned model
seat
not a seat



[Shotton, Blake, Cipolla 05]



[Shotton, Winn, Rother, Criminisi 06 + 08]
[Winn & Shotton 06]

[Shotton, Johnson, Cipolla 08]

A call to action

Thu 11/09/2008 20:19

Hi Jamie,

I work on Xbox Incubation and I noticed some work you’ve done on visual recognition using contours (http://jamie.shotton.org/work/research.html). I was hoping to be able to discuss an important scenario we are trying to solve with you. Would you be able to chat?

Thanks,

- Mark

A call to action

Thu 11/09/2008 21:50

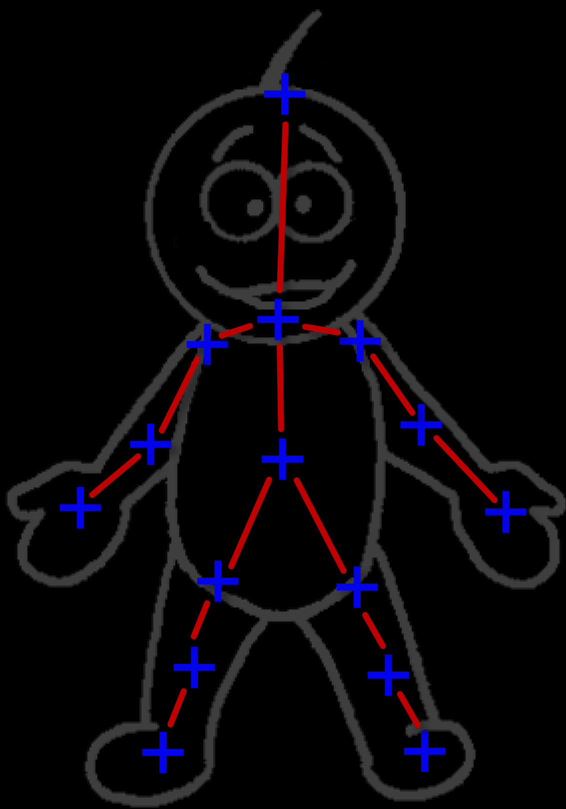
Hey Jamie,

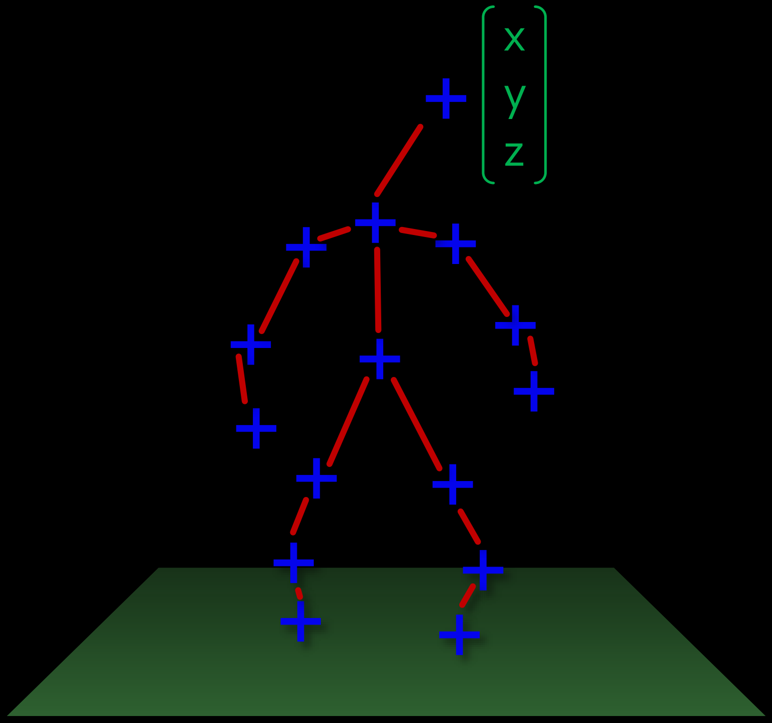
Can you talk right now? ☺

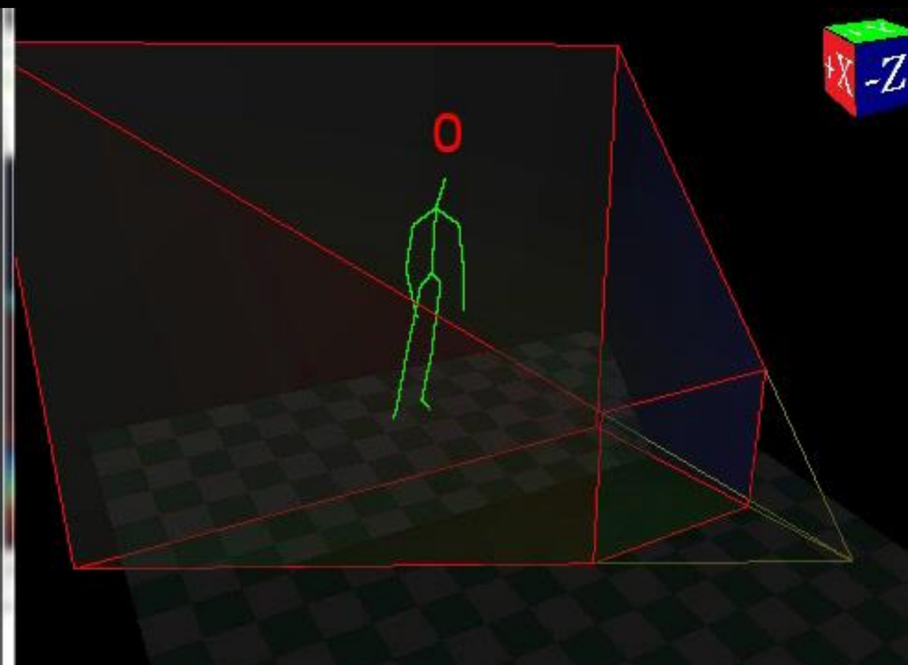
- Mark

PROJECT
NATAL

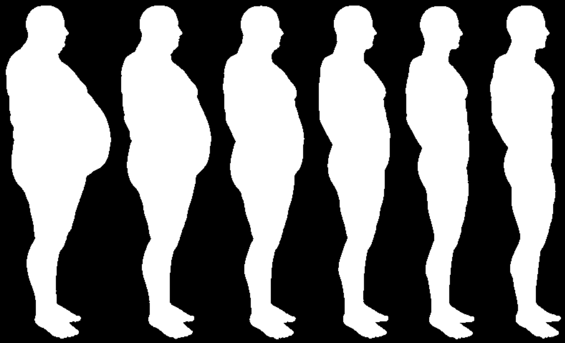
Human pose estimation

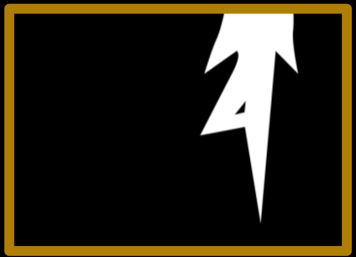


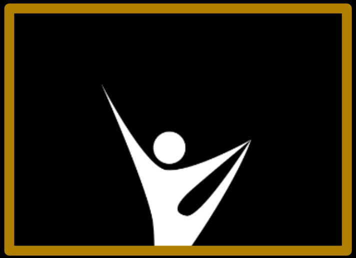



0
+X
-Z

Why is it hard?







Motion capture

[Vicon]

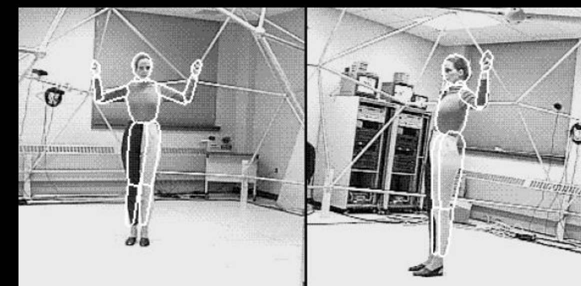
[Xsens]

- ☑ very accurate
- ☑ high frame rate
- ☒ suit / sensors
- ☒ expensive
- ☒ large space
- ☒ calibration

Computer vision approaches

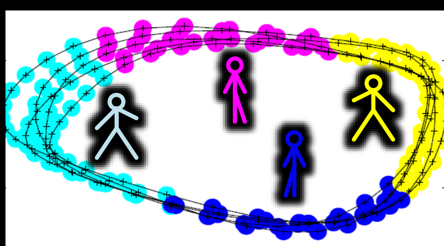
[Mori et al. 04]

Monocular, natural images ⟷ Stereo & 3D images



[Gavrila & Davis 96]

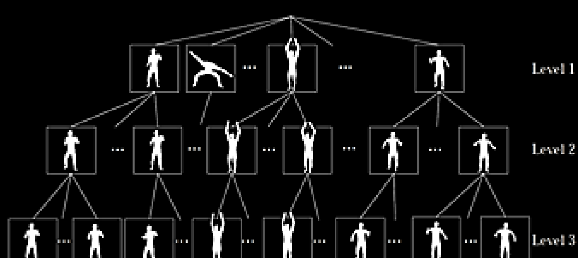
[Agarwal & Triggs 04]



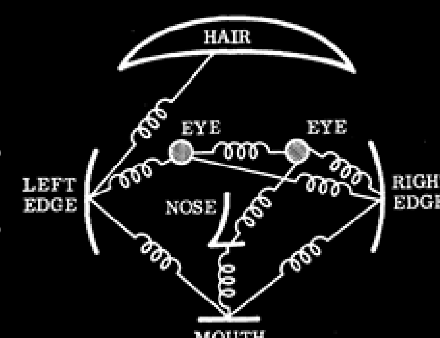
Tracking motion ⟷ Frame-by-frame

[Bourdev & Malik 09]

[Okada & Stenger 08]



Whole body ⟷ Parts models



[Fischler & Elschlager 73]

Requirements

- Human pose estimation
  - any pose
  - any body shape & size

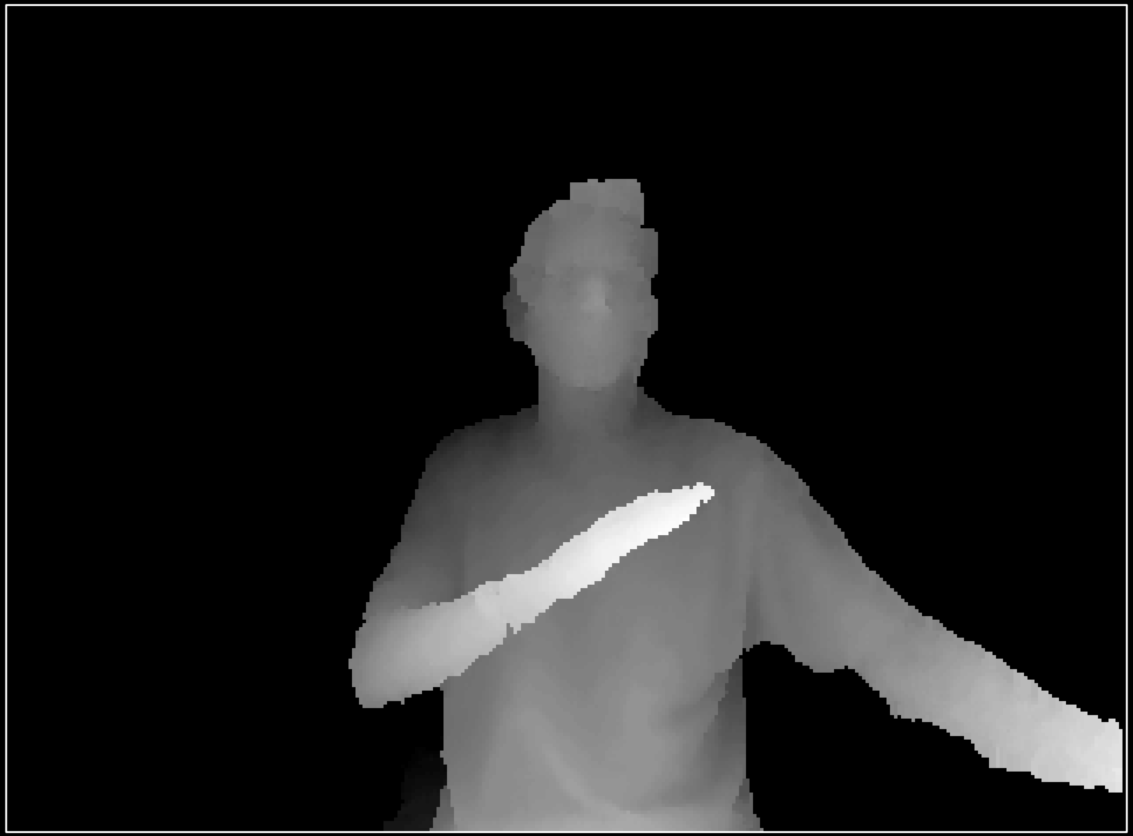
- No calibration or instrumentation of the user

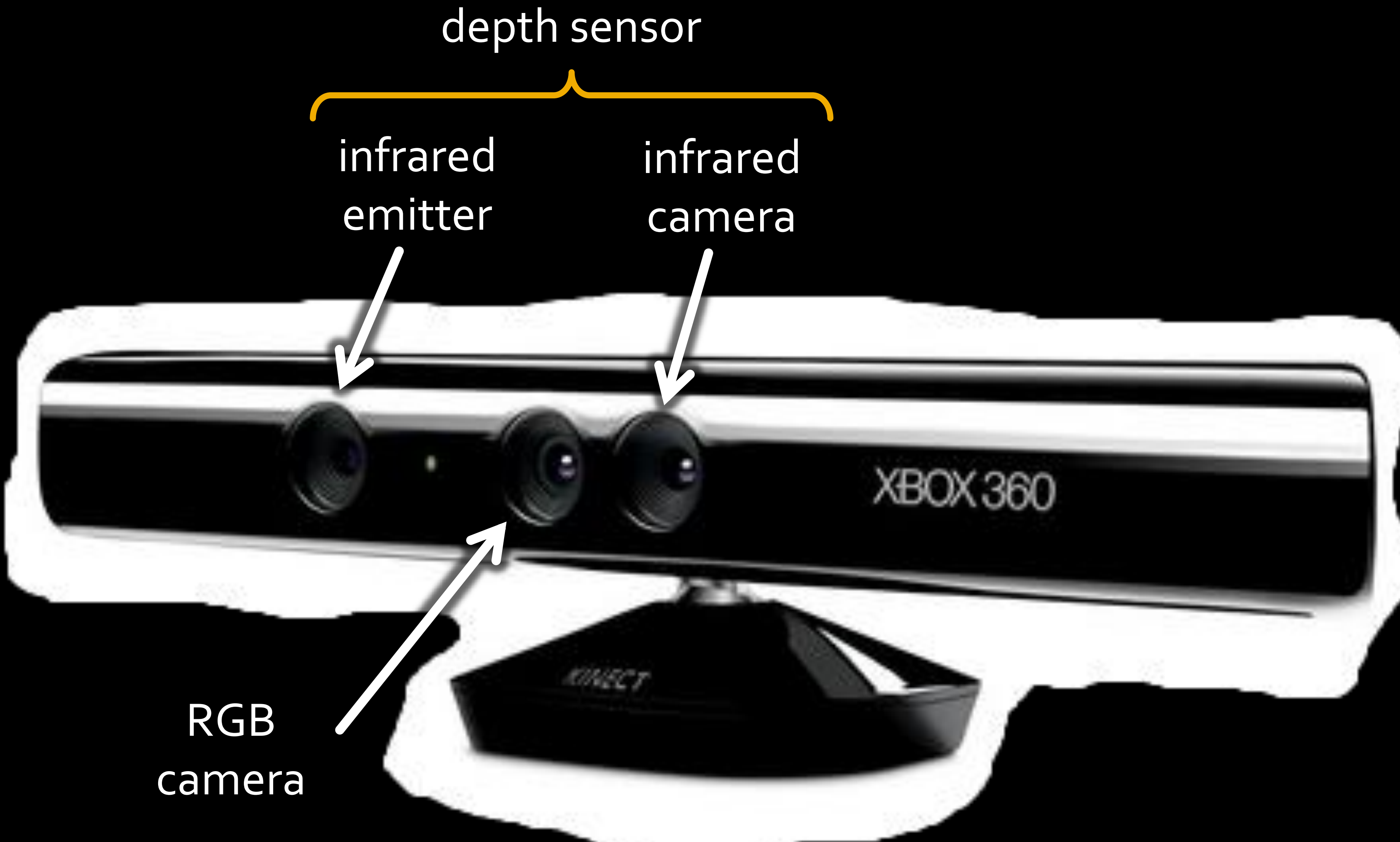
- Must "never fail"

- Must run at real time in 10%
  of Xbox 360 (2005 era hardware)

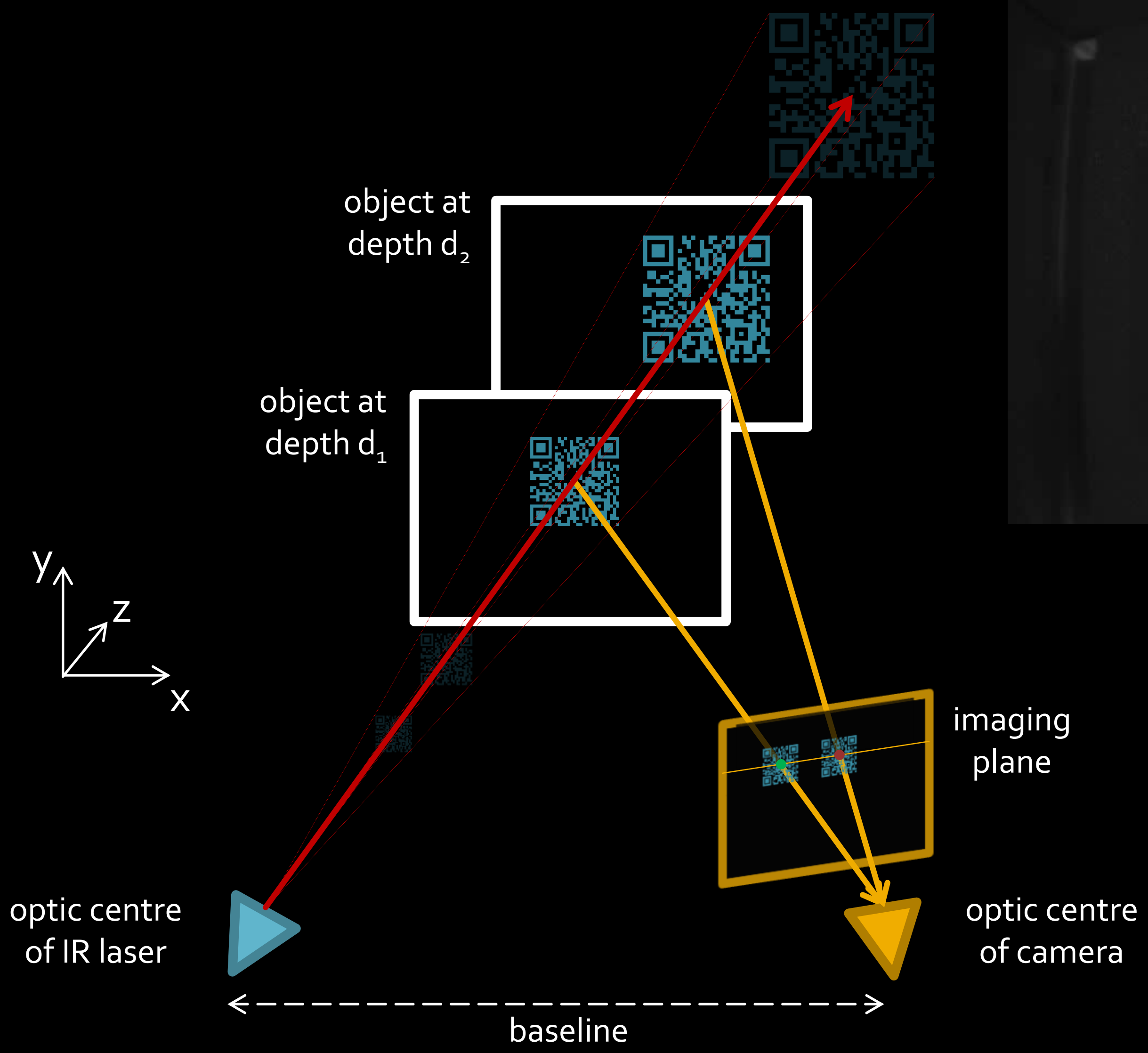
- Must ship "Holiday 2010"

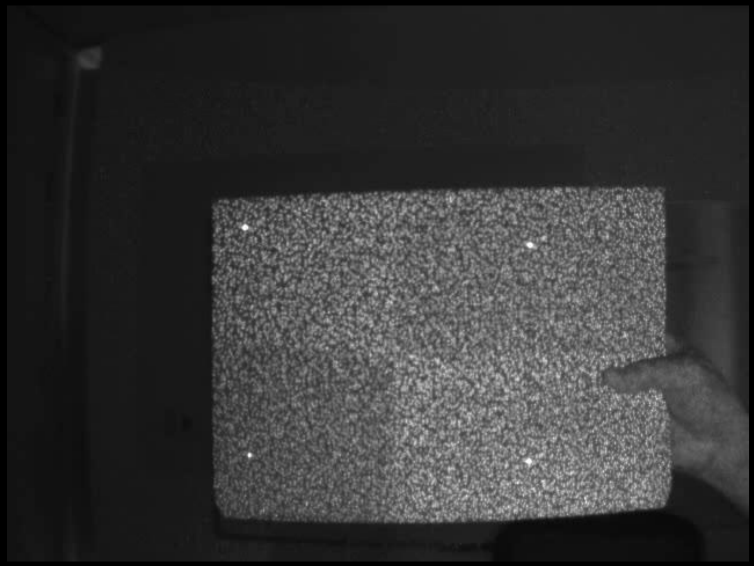
The depth camera



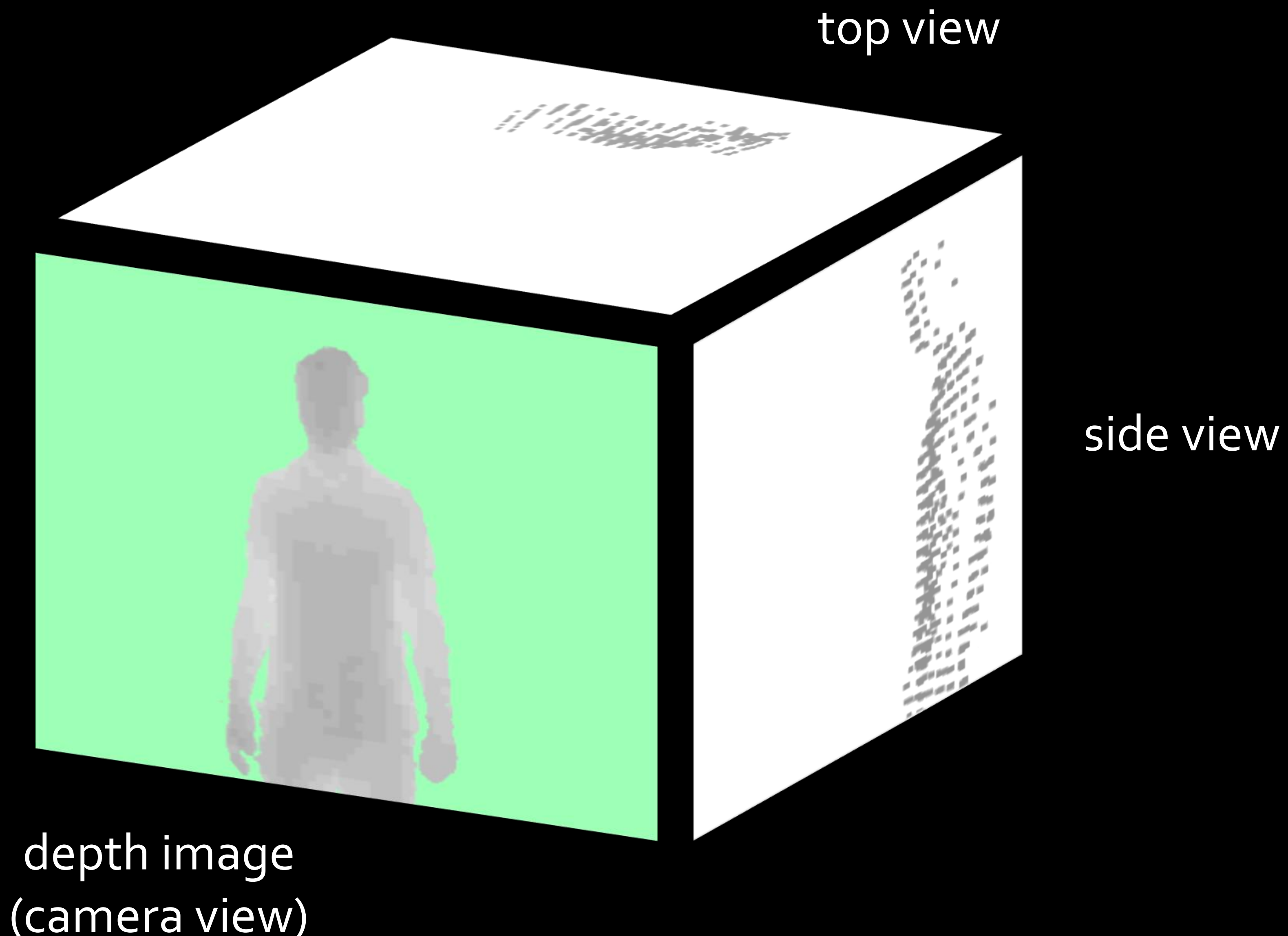

depth sensor
infrared emitter
infrared camera
RGB camera
XBOX 360
KINECT

Structured light





The Kinect camera



RGB vs depth for pose estimation

RGB	**Depth**
☒ Only works well lit	☑ Works in low light
☒ Background clutter	☑ Person ‘pops’ out from bg
☒ Scale unknown	☑ Scale known
☒ Clothing & skin colour	☑ No colour or texture variation

Related work using 3D input

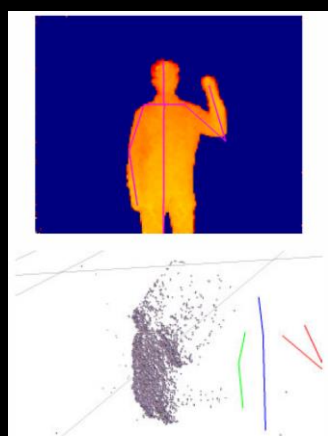
[Anguelov *et al*. 05]

[Grest *et al*. 05]

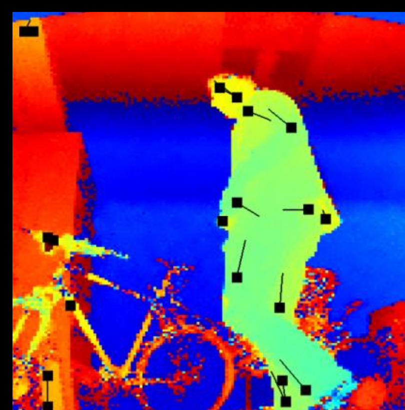
[Knoop *et al*. 06]

[Zhu & Fujimura 07]

[Kalogerakis *et al*. 10]



[Siddiqui & Medioni 10]

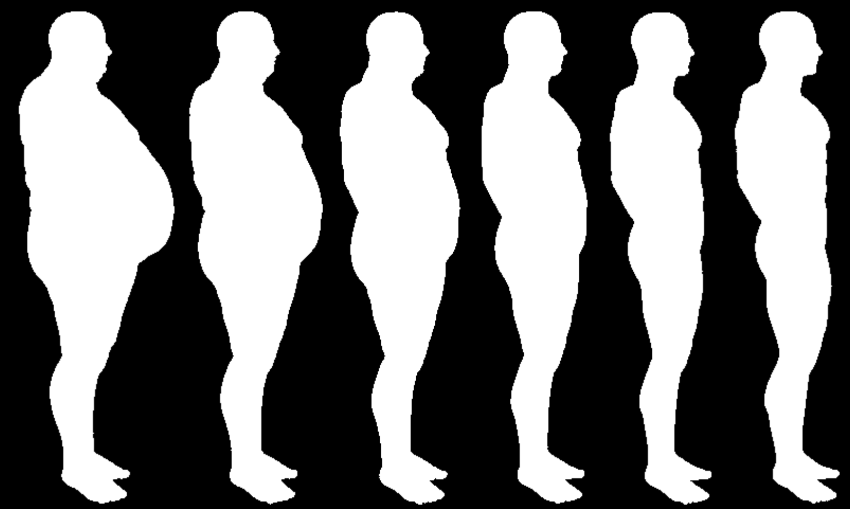


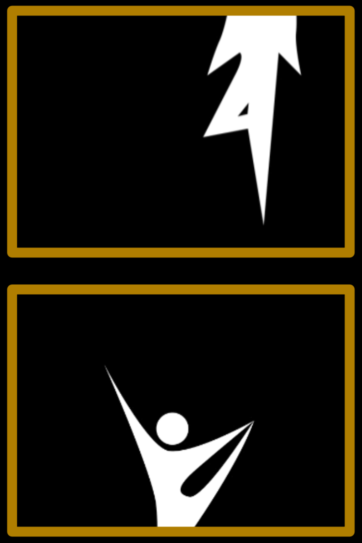
[Plagemann *et al.* 10]

[Ganapathi *et al.* 10]

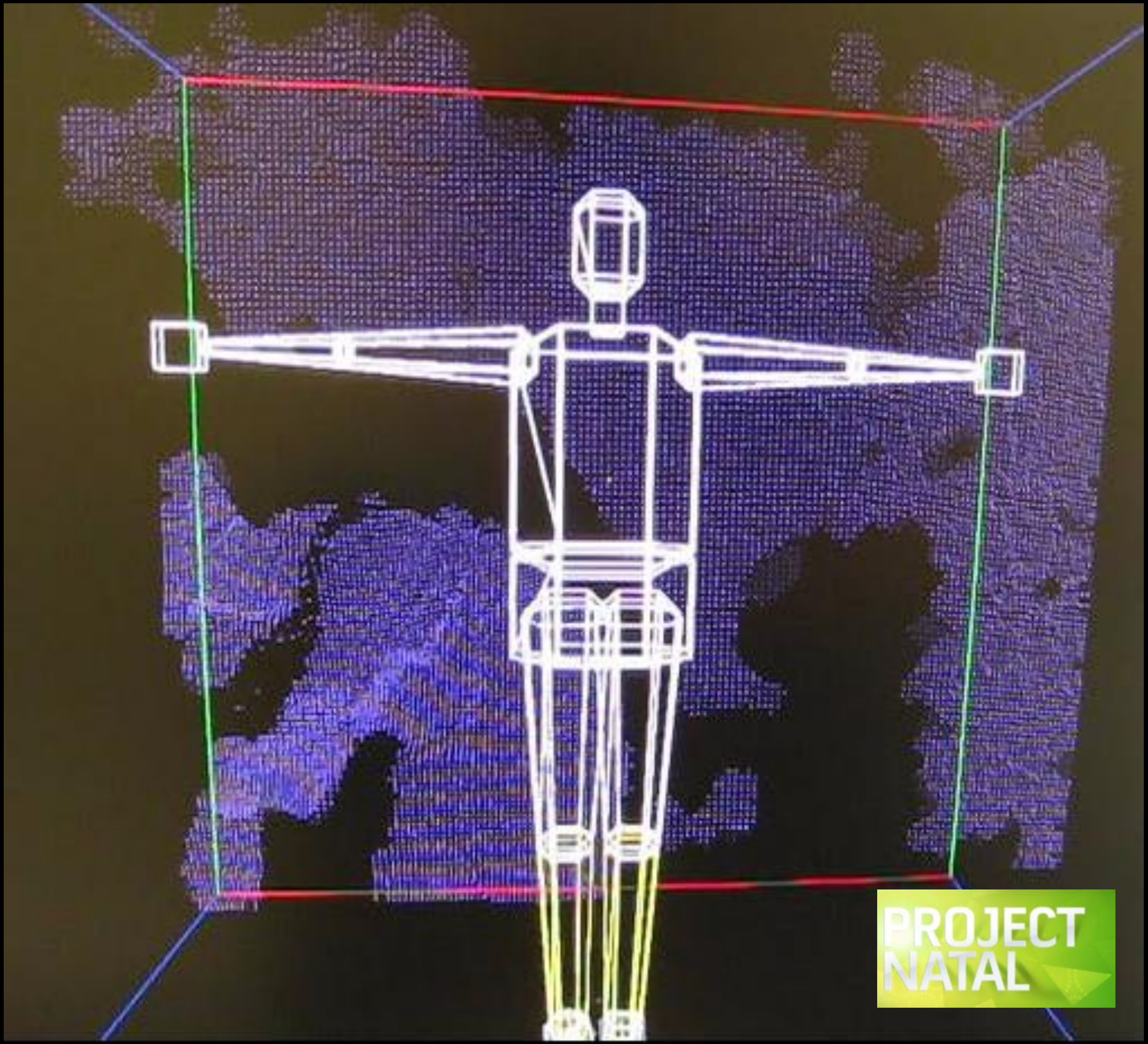
[Baak *et al*. 11]

Problems remaining



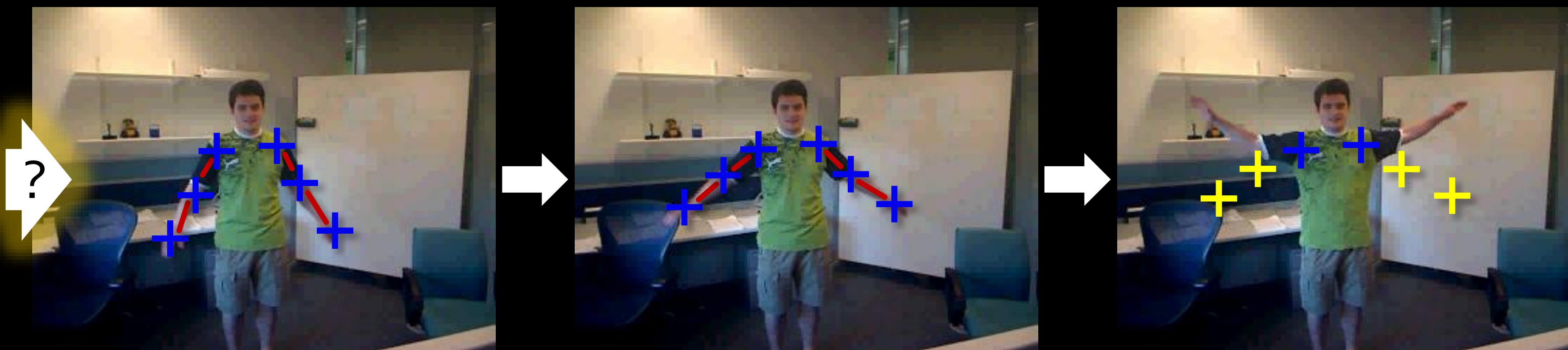


Tracking



Tracking

time t time $(t+1)$ time $(t+2)$



slow movement faster movement

☑ Smooth, realistic output

☒ Initialisation

☒ Prone to catastrophic failure

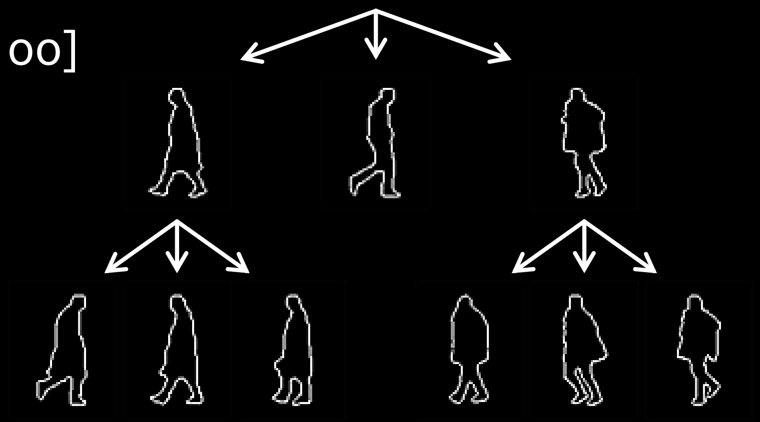
Our mission

- Auto-initialise tracking algorithm
- Detect and recover from failures

Matching whole poses

☑ An image of a *whole* person is very indicative of the person's pose

[Gavrila 00]



[Okada & Stenger 08]

☒ Massive search space of whole poses

- exponential in number of joints
  - ➢ hard to scale up

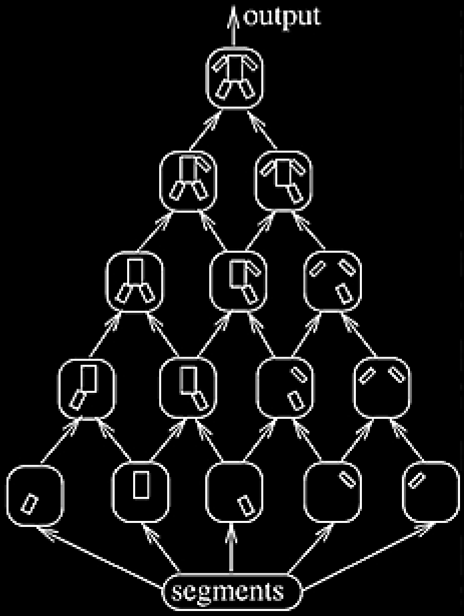
Matching whole poses

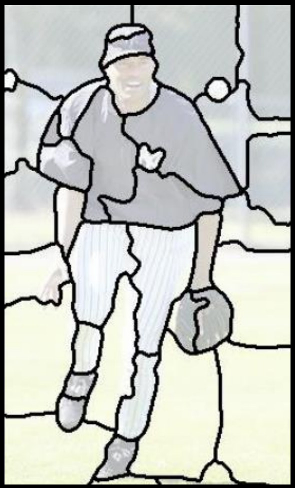
- ☒ Massive search space of whole poses
  - exponential in number of joints
  - ➢ hard to scale up

Parts-based models

- Find parts of the body separately
- Stitch them together efficiently

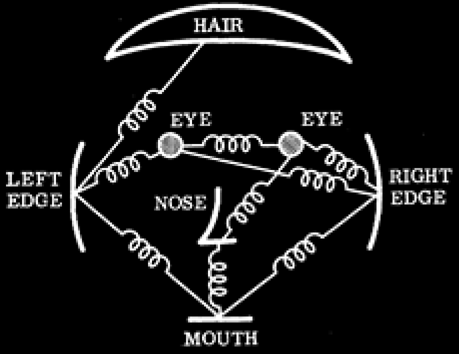
[Ioffe & Forsyth 01]





[Mori *et al.* 04]

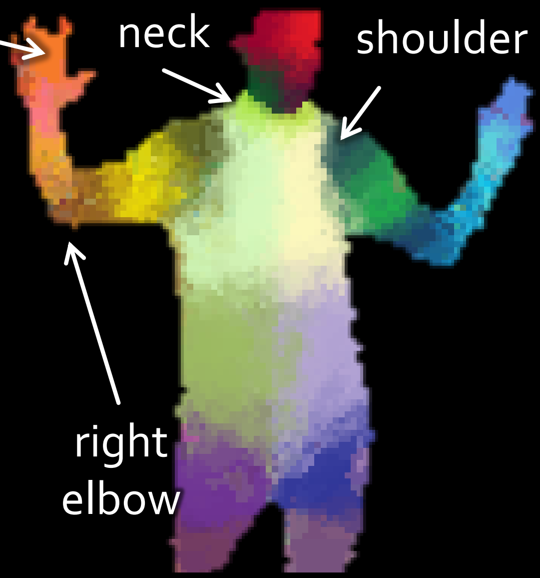
[Fischler & Elschlager 73]
[Felzenszwalb & Huttenlocher 05]
[Ferrari *et al.* 08]



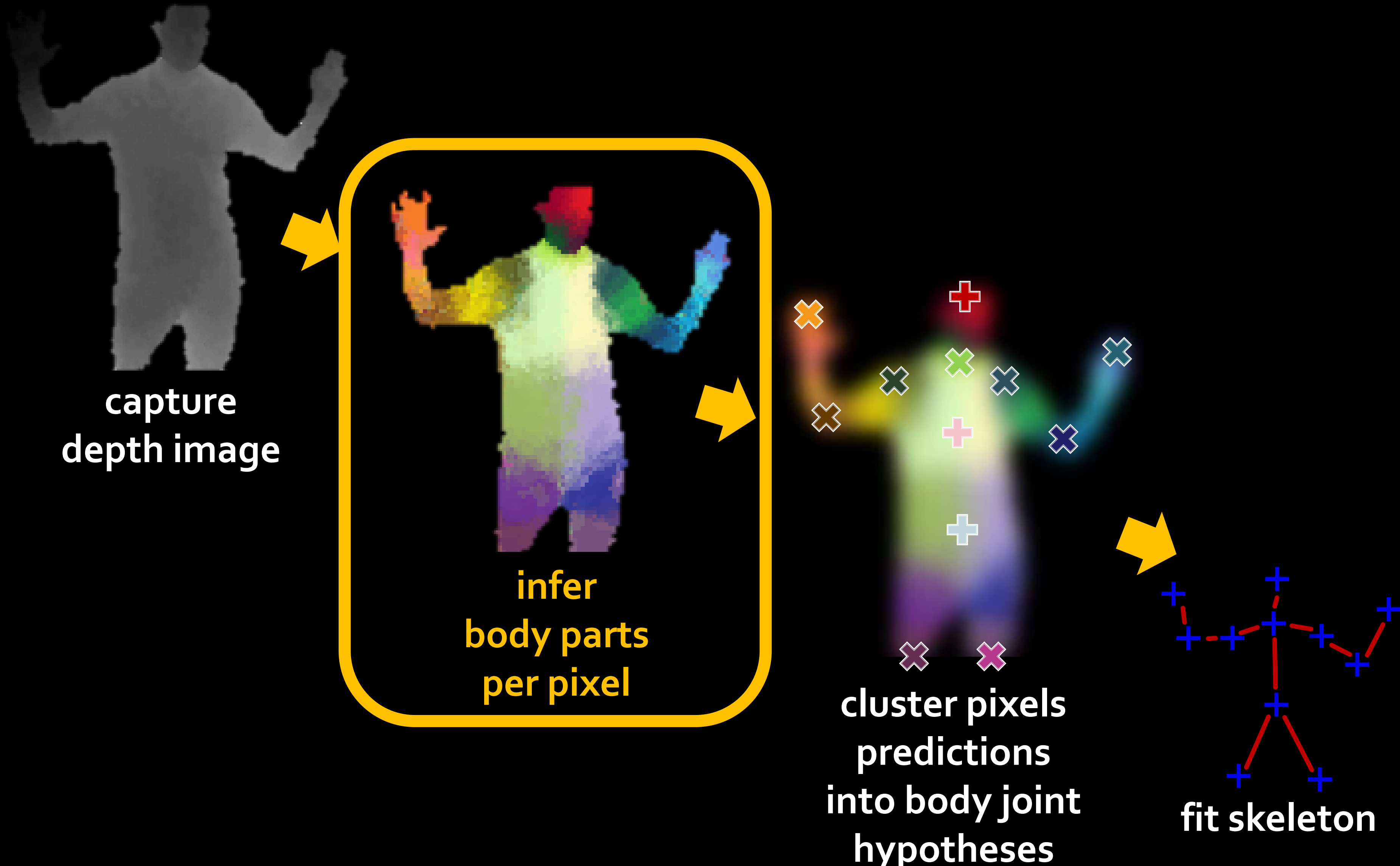
[Bourdev & Malik 09]

Our solution: body part recognition

- Local pose estimate of parts
  - each pixel & each body joint treated independently
  - reduced training data and computation time
- No temporal information
  - frame-by-frame
- Very fast
  - simple depth image features
  - parallel decision forest classifier

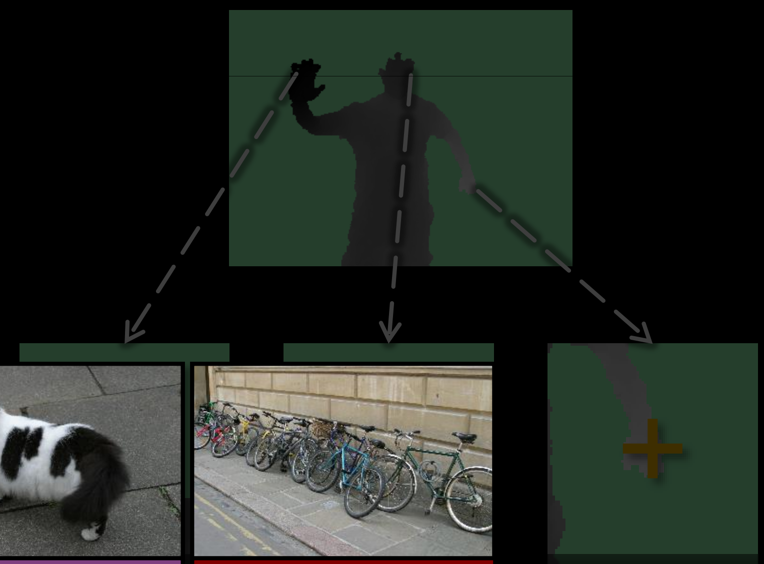


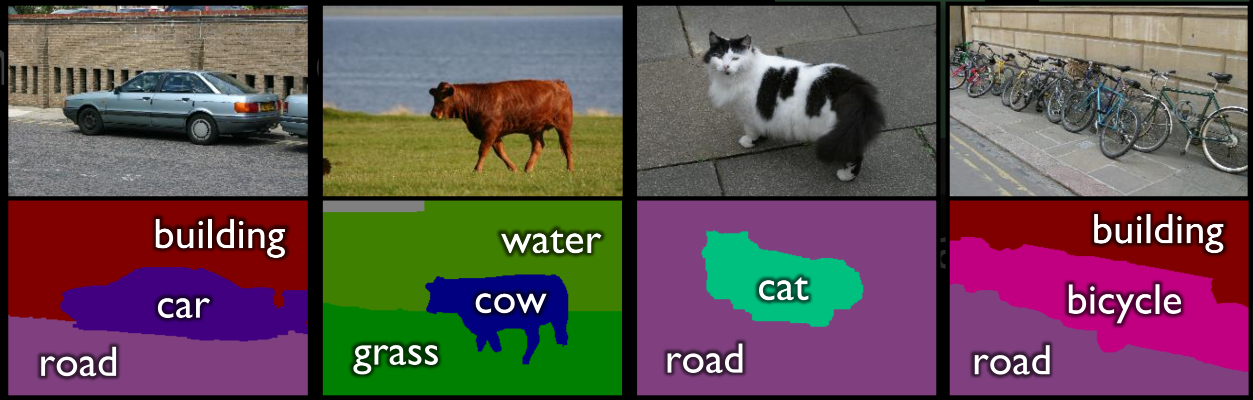
The Kinect pose estimation pipeline



Classifying pixels

- Compute $\mathrm{P}(c \mid w)$
  - body part c
  - in





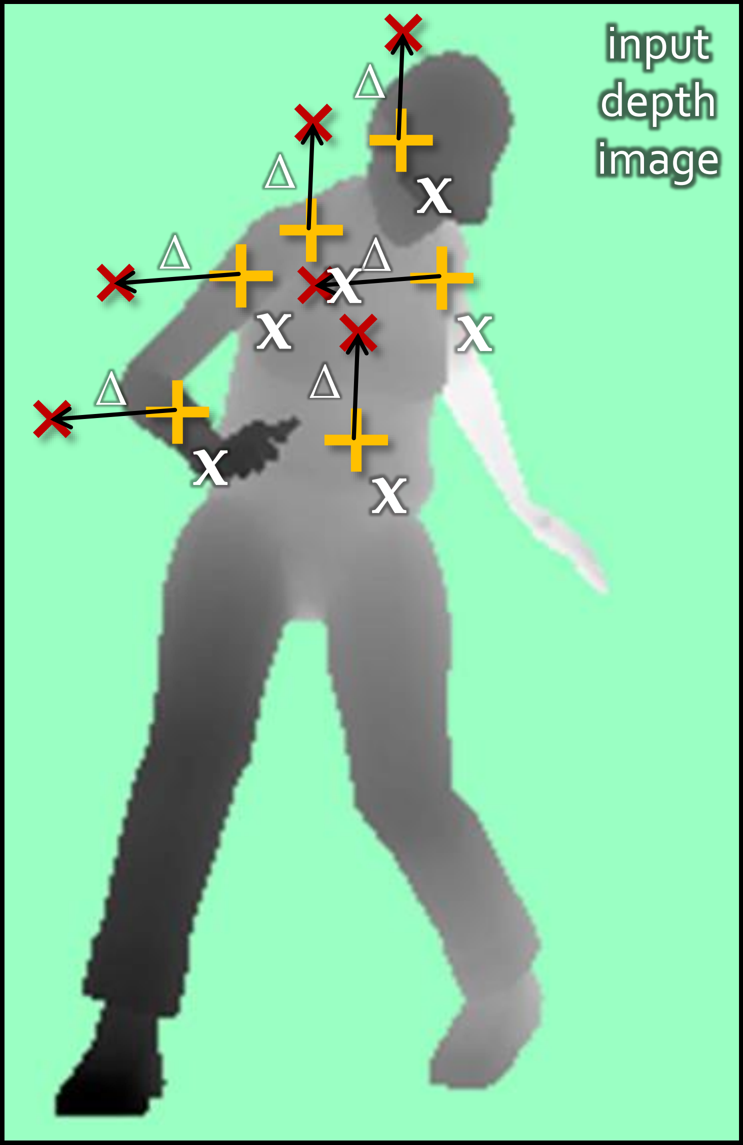
s move
fier

Train by example to be invariant to:

Training data

Fast depth image features

- Depth comparisons
  - very fast to compute

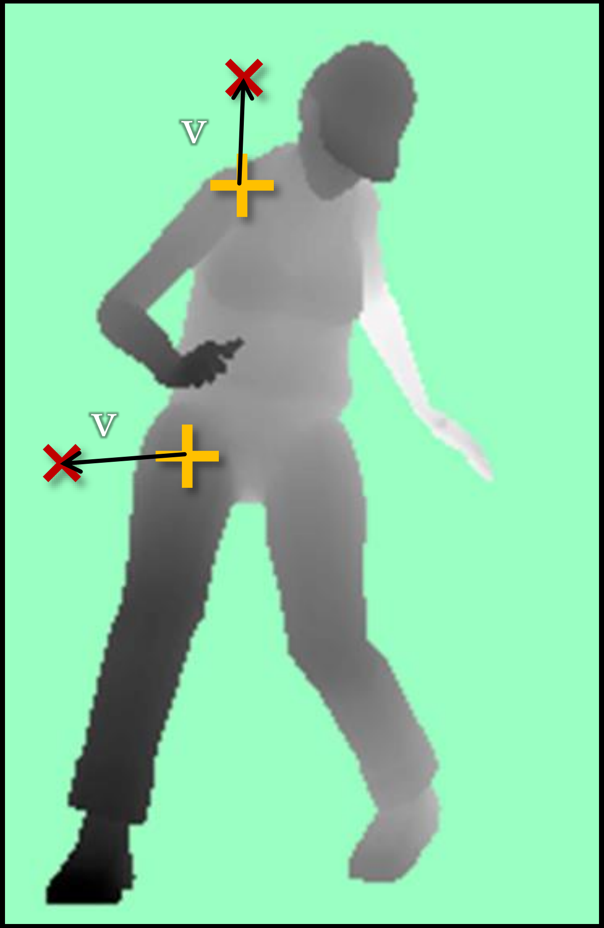


Background pixels
d = large constant

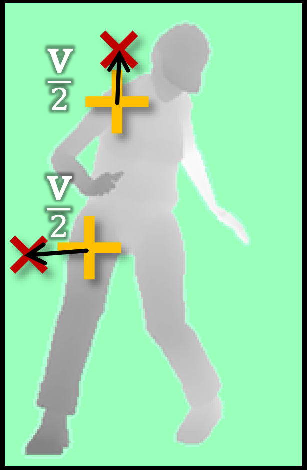
Depth invariance

$$f(I, \mathbf{x}) = d_I(\mathbf{x}) - d_I(\mathbf{x} + \Delta)$$

$$\Delta = \underbrace{\frac{\mathbf{v}}{d_I(\mathbf{x})}}_{\text{scales inversely with depth}}$$

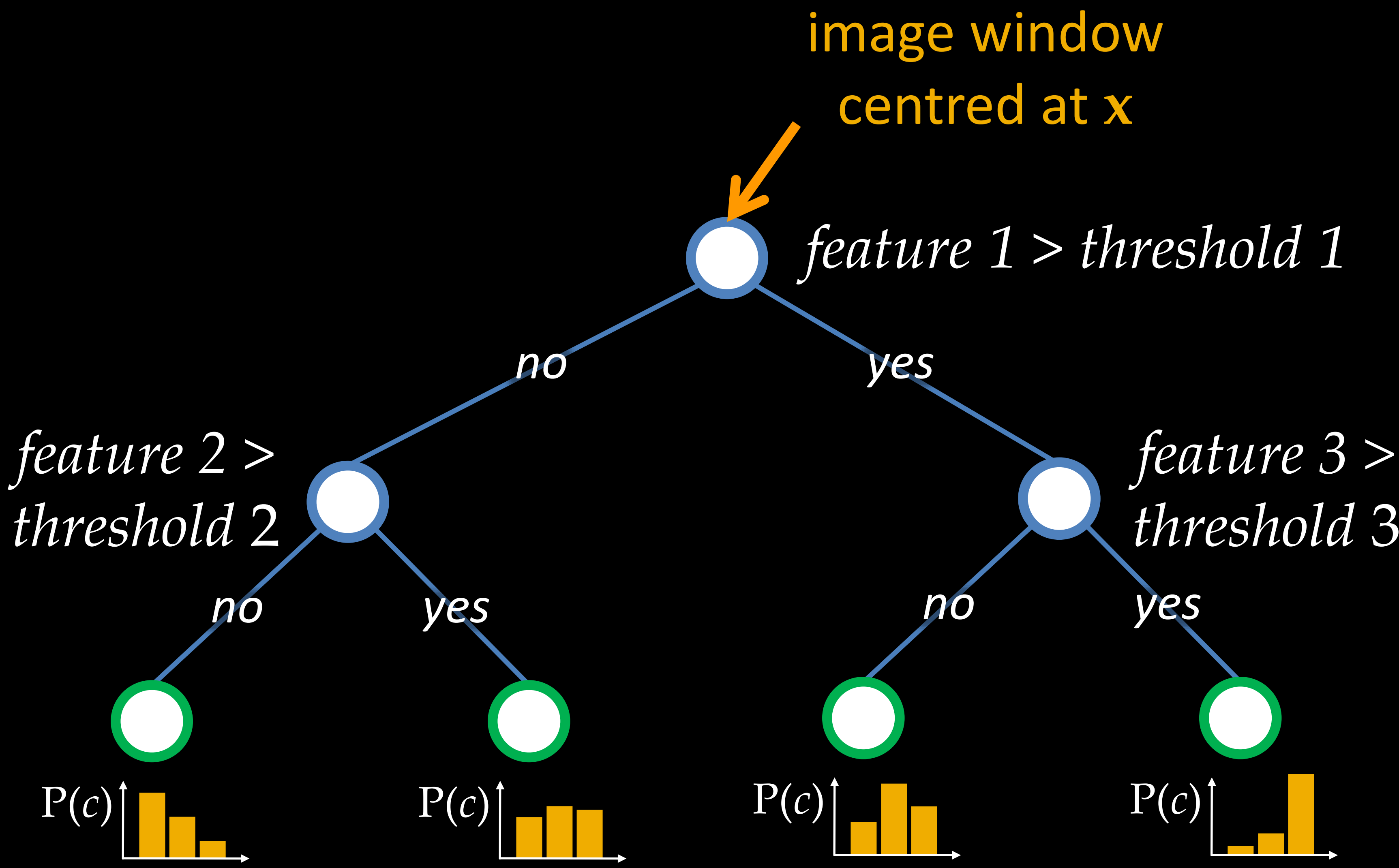


Average depth 1m



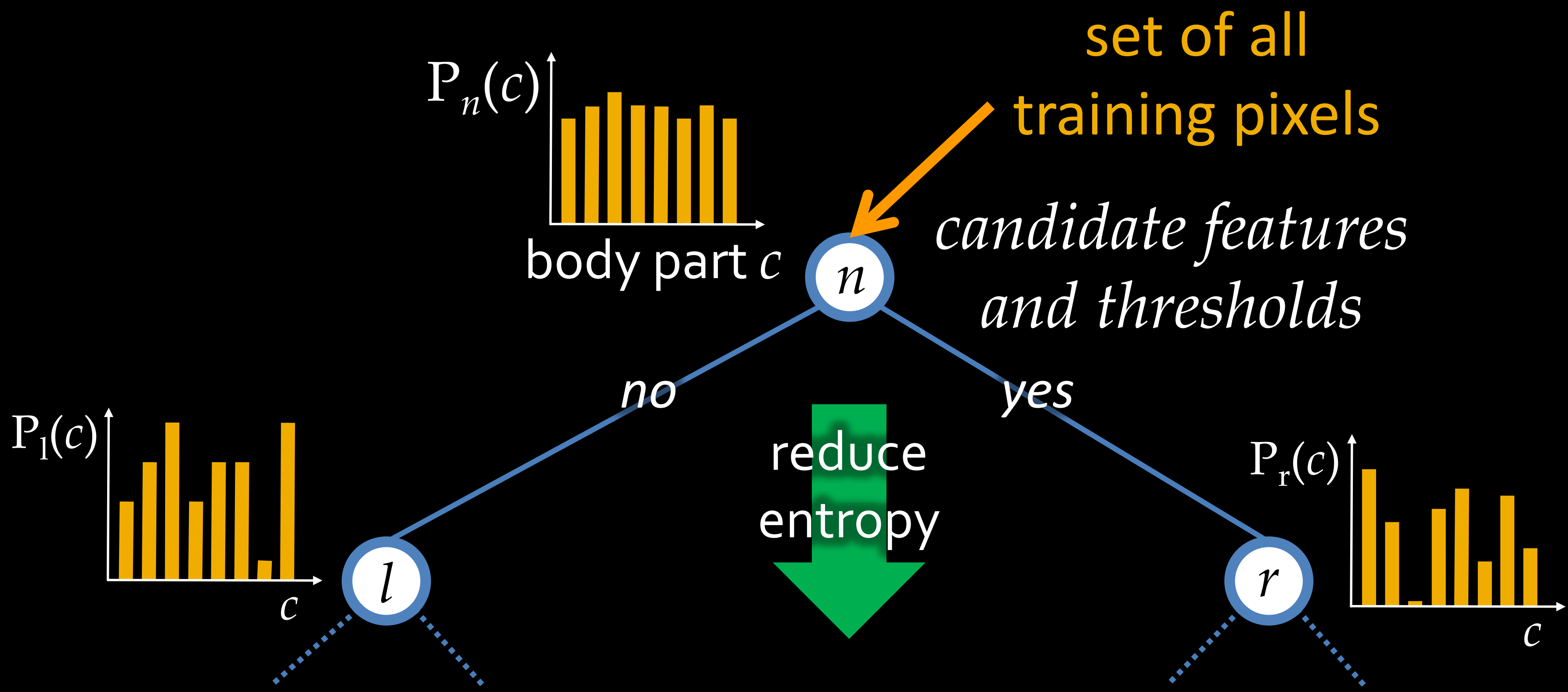
Average depth 2m

Decision tree classification



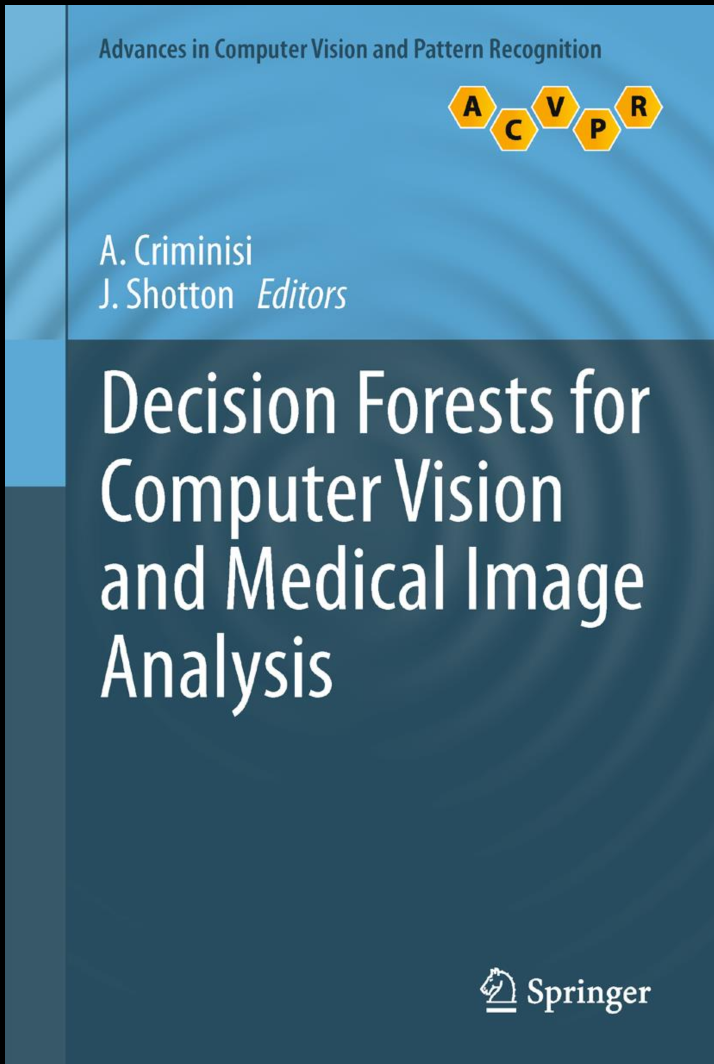
Training decision trees

[Breiman *et al.* 84]



Take (*feature*, *threshold*) that most reduces Shanon Entropy

Goal: drive entropy at leaf nodes to zero



See our new book!

- Theory – Tutorial & Reference
- Practice – Invited Chapters
- Software and Exercises
- Tricks of the Trade

A. Criminisi & J. Shotton
Springer, 2013

Early results

Scaling up: synthetic training data

Record mocap
100k poses

Retarget to several models

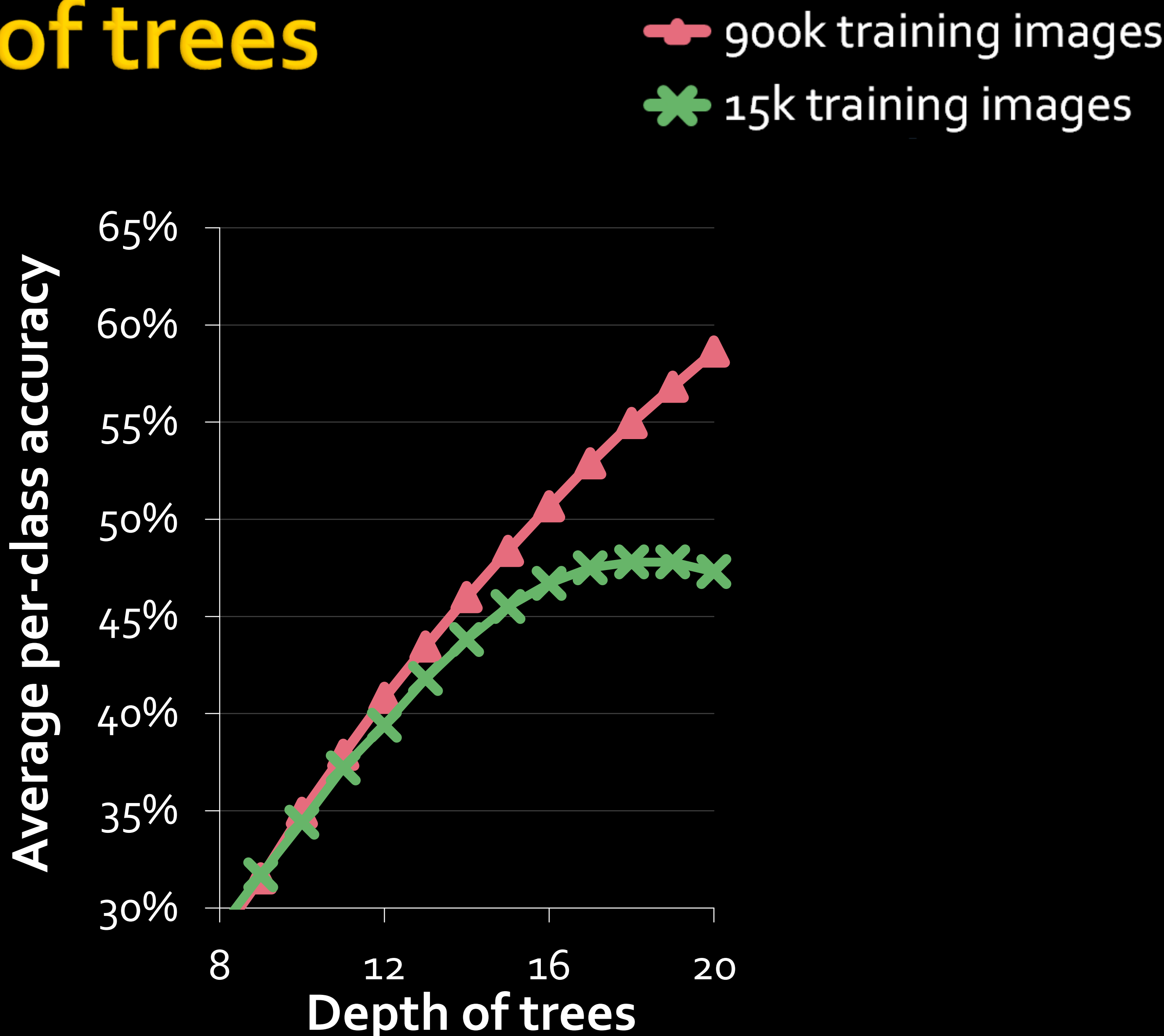
Render (depth, body parts) pairs

Depth of trees

input depth | ground truth parts | inferred parts (soft)

depth 18

Depth of trees

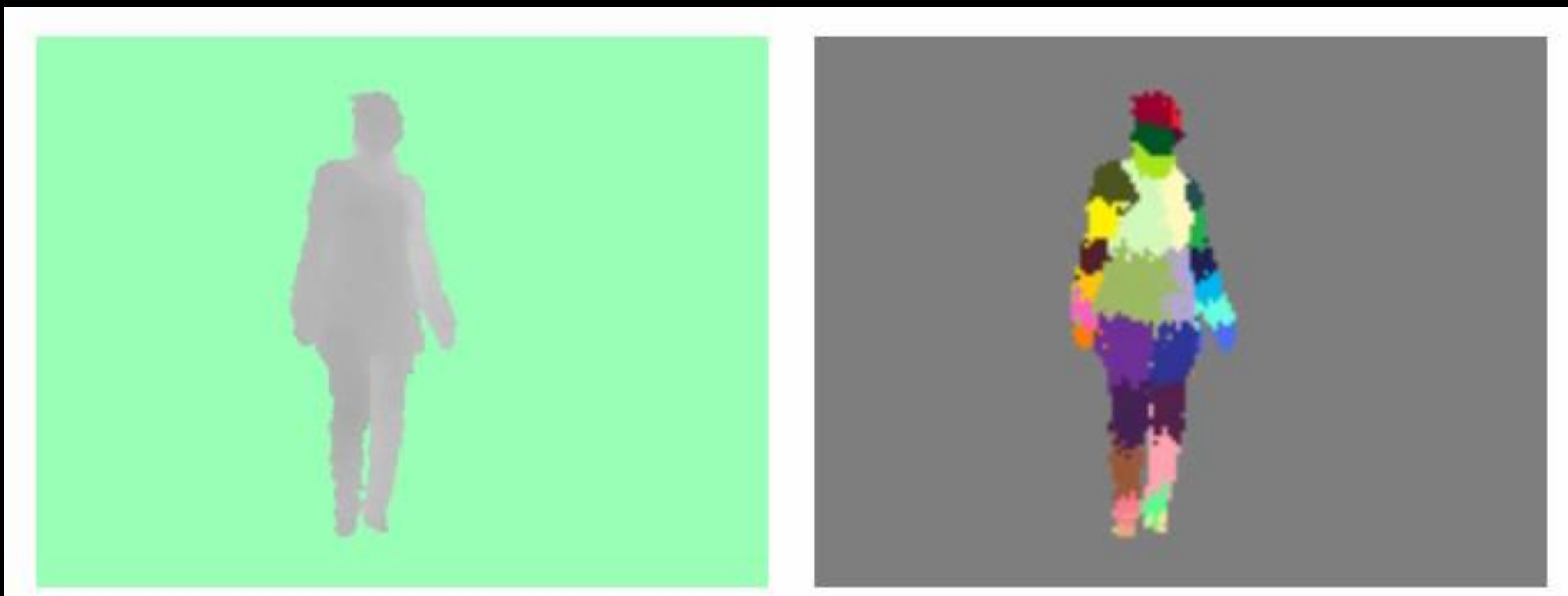


Scaling up

- 31 body parts
- 3 Trees to depth 20
  - ~3 x 2^{20} nodes
- Training
  - ~1,000,000 training images
  - ~2,000 pixels per image
  - ~10,000 features tested per node

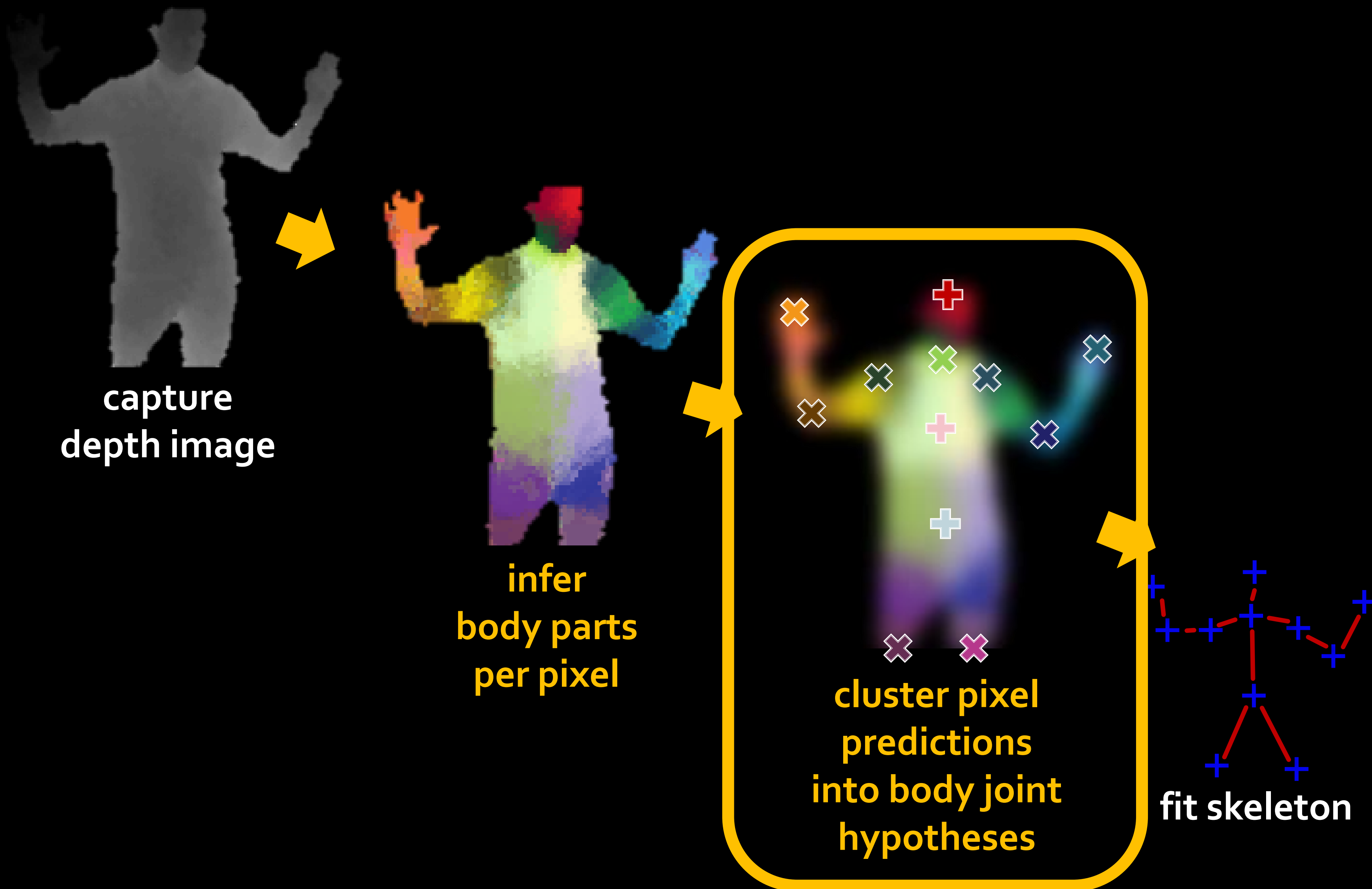
- Very fast at test time
  - only ~60 image feature evaluations per pixel
  - readily parallelisable for GPU [Sharp 08]

input depth | inferred body parts

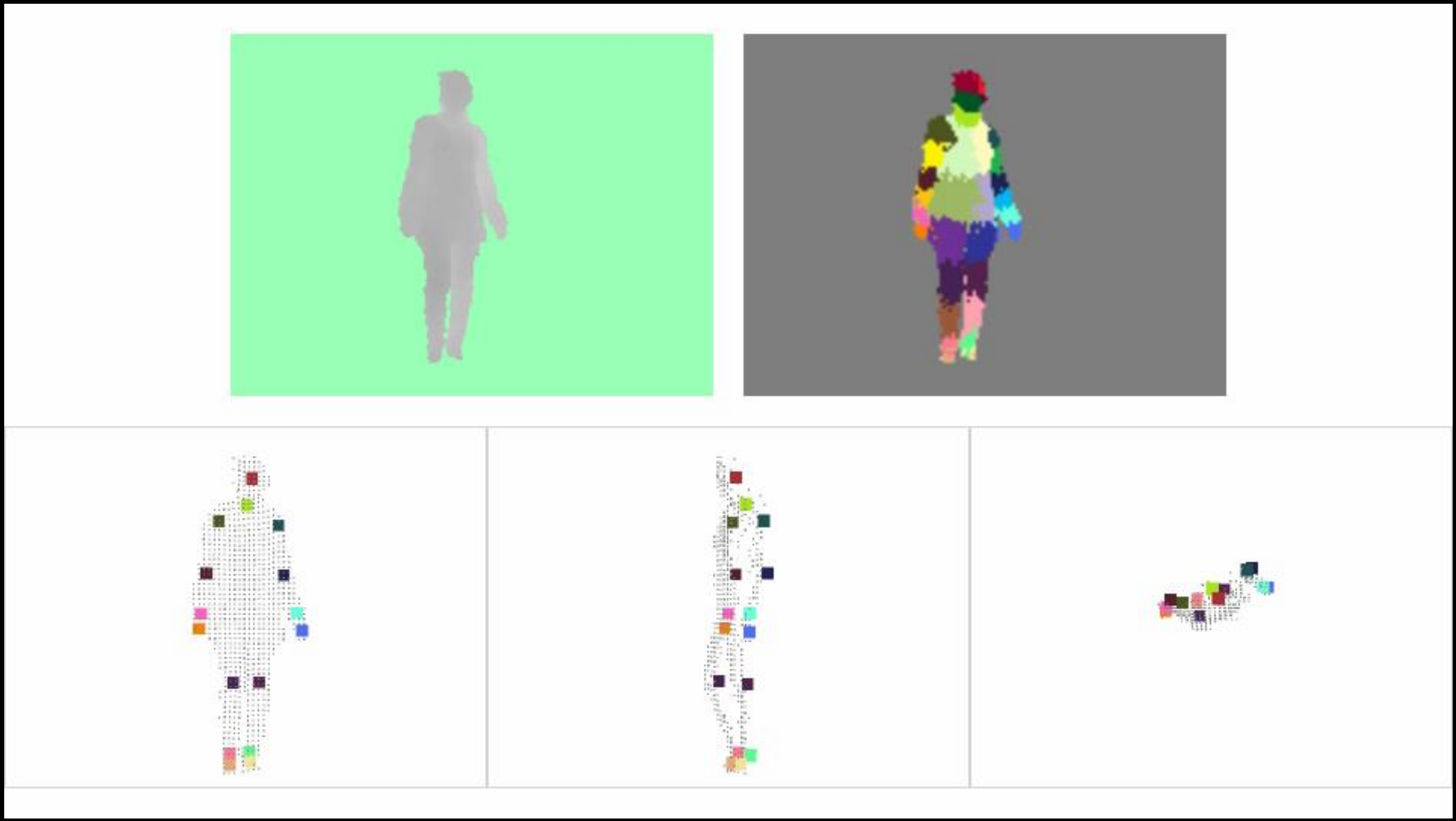


no tracking or smoothing

The Kinect pose estimation pipeline



input depth inferred body parts

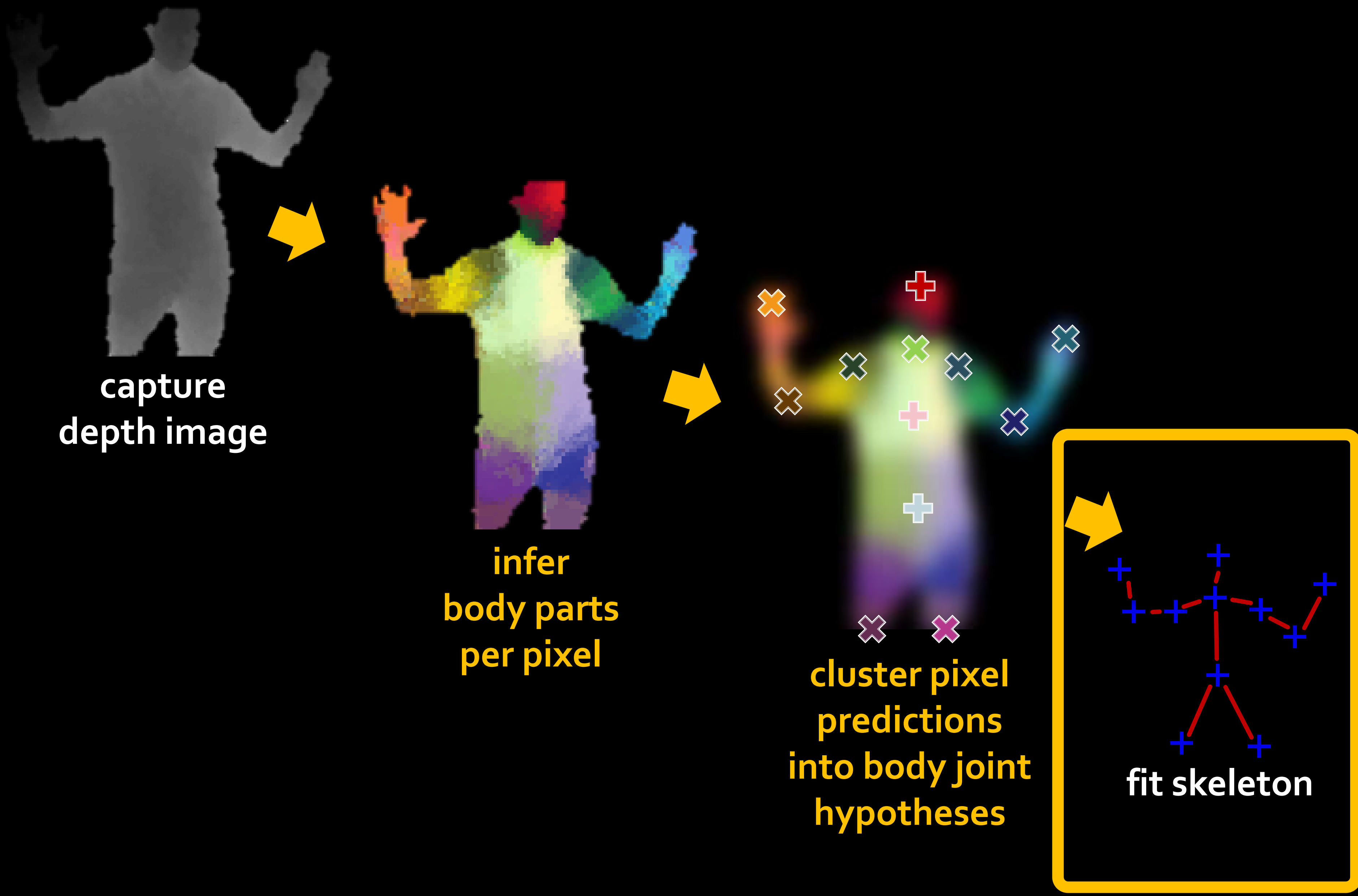


front view side view top view

inferred joint positions

no tracking or smoothing

The Kinect pose estimation pipeline



KINECT launch

Microsoft Kinect 'fastest-selling device on record'

Microsoft has sold more than 10 million Kinect sensor systems since launch on 4 November, and - according to Guinness World Records - is the fastest-selling consumer electronics device on record.

The sales figures outstrip those of both Apple's iPhone and iPad when launched, Guinness said.

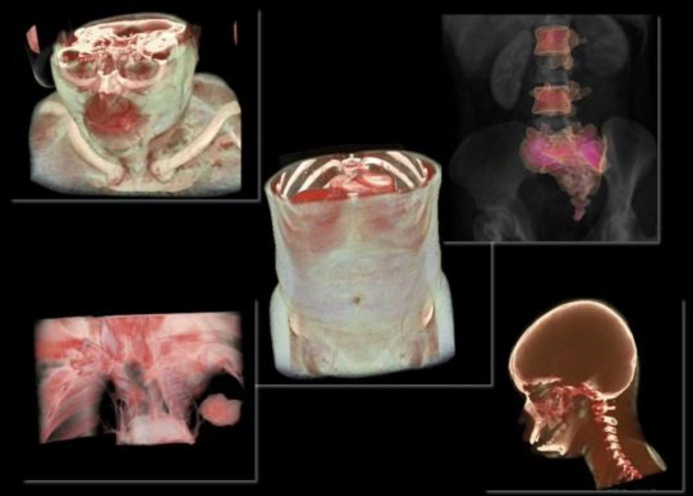
Kinect is an infrared camera add-on for Microsoft's Xbox 360 games console that allows it to track body movements.

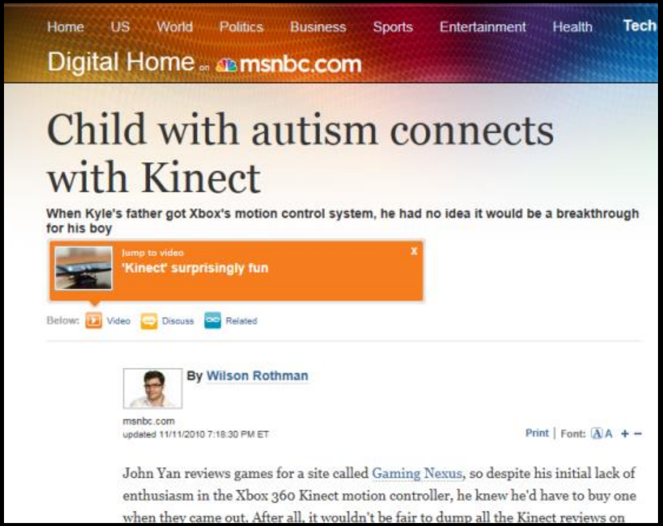
The popularity of the Kinect has helped to boost sales of games, Microsoft says


XBOX 360
KINECT

KINECT for Windows

A new world for research





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Child with autism connects with Kinect

When Kyle's father got Xbox's motion control system, he had no idea it would be a breakthrough for his boy

Jump to video
'Kinect' surprisingly fun

Below: Video Discuss Related

By Wilson Rothman

msnbc.com
updated 11/11/2010 7:18:30 PM ET

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John Yan reviews games for a site called Gaming Nexus, so despite his initial lack of enthusiasm in the Xbox 360 Kinect motion controller, he knew he'd have to buy one when they came out. After all, it wouldn't be fair to dump all the Kinect reviews on

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31 May 2012 Last updated at 06:39 GMT

Share

Trial of "touchless" gaming technology in surgery

By Adam Brimelow
Health Correspondent, BBC News

Doctors in London are trialling "touchless" technology, often used in TV games, to help them carry out delicate keyhole surgery.

The system allows them to manipulate images with their voice and hand-gestures rather than using a keyboard and mouse.

Surgeons say it gives them more control and avoids disruption.

The technology could be a valuable aid to sugery

KINECTFusion

Joint work with Shahram Izadi, Richard Newcombe, David Kim, Otmar Hilliges, David Molyneaux, Pushmeet Kohli, Steve Hodges, Andrew Davison, Andrew Fitzgibbon.

SIGGRAPH, UIST and ISMAR 2011.

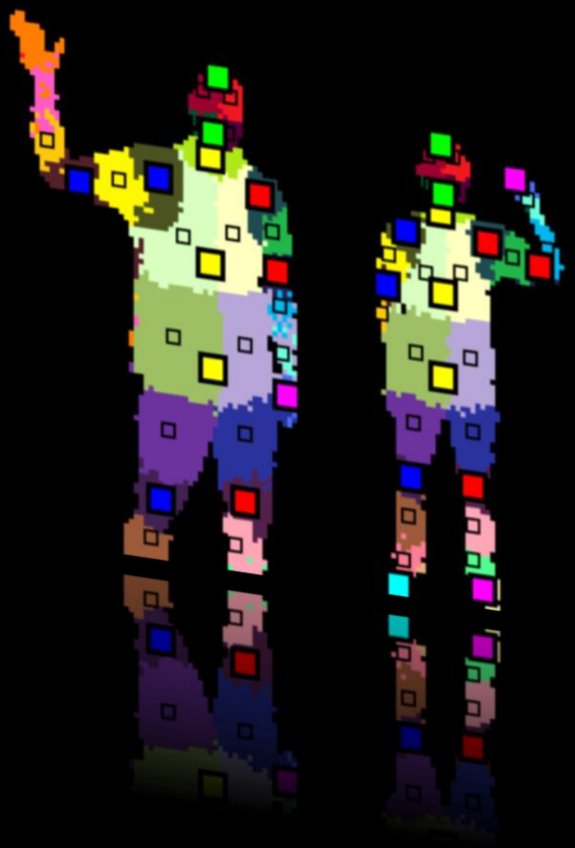
Hand Grip/Release Detection

Hand Grip/Release Detection

Take home thoughts

- Blue skies PhD research
  contributed heavily to Kinect's success
- Machine learning
  can solve hard problems through big data
- Kinect opening up myriad applications

KINECT



With thanks to:

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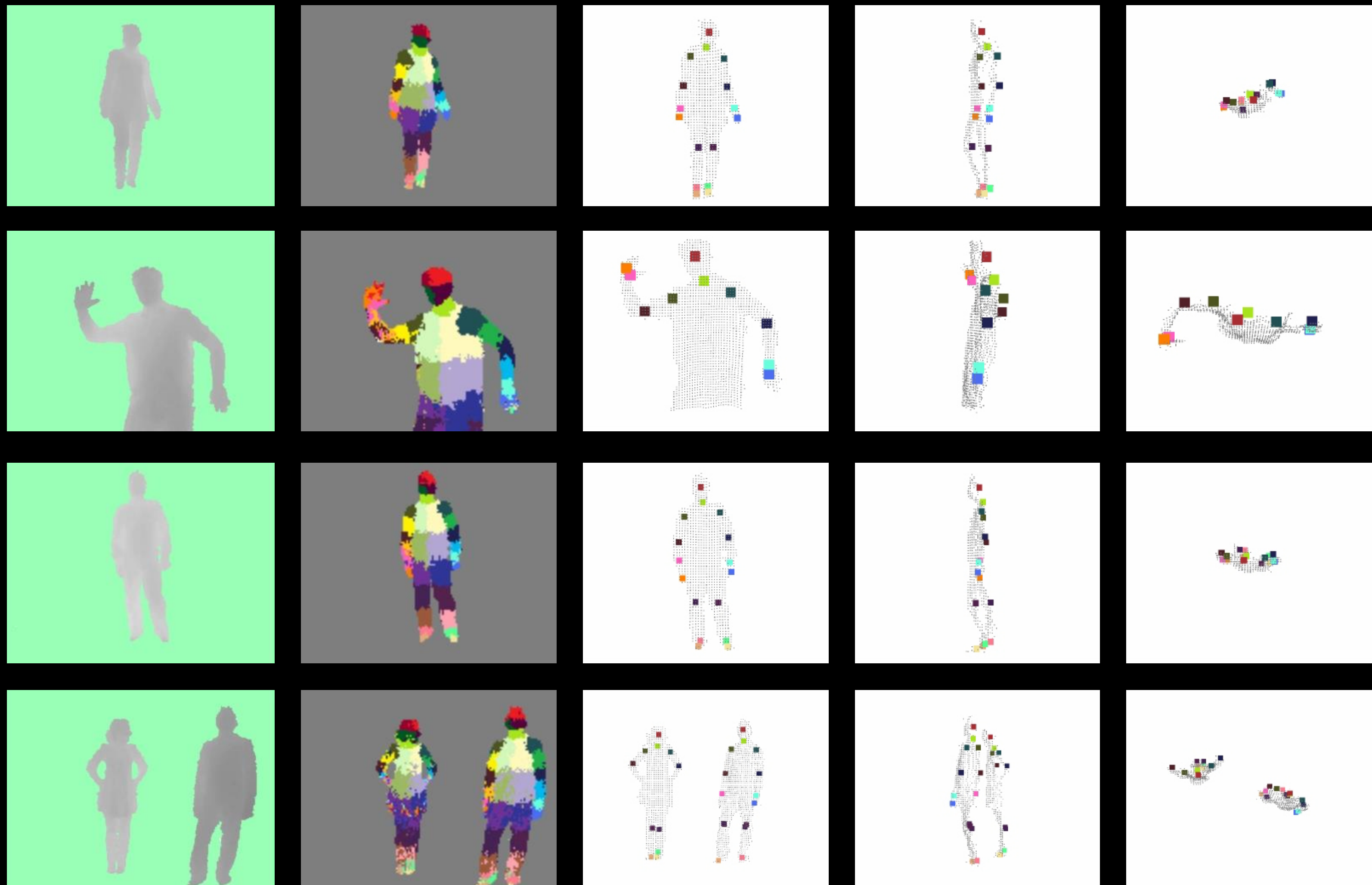
The whole Kinect team, especially: Mark Finocchio, Alex Kipman, Ryan Geiss, Richard Moore, Robert Craig, Momin Al-Ghosien, Matt Bronder, Craig Peeper



http://www.microsoft.com/en-us/kinectforwindows/

Microsoft Research

KINECT