Lifting from the Deep:
Convolutional 3D Pose Estimation from a Single Image

Denis Tomè Chris Russell Lourdes Agapito

We introduce a novel approach to solve the problem of

3D human pose estimation

from a single RGB image

Input image

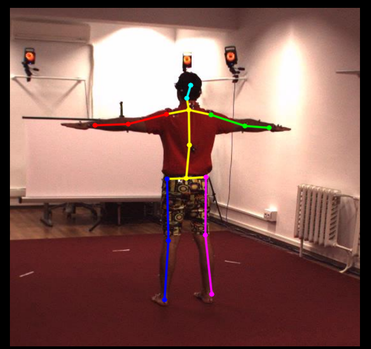
Output 3D Pose

Our method reasons **jointly** about 2D joint estimation

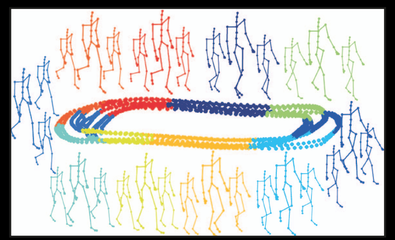
and 3D pose reconstruction to **improve both tasks**.

Our approach

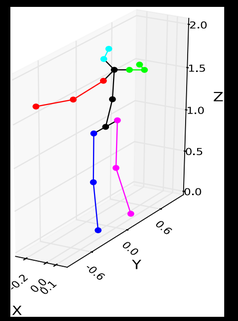
- First, we learn a **probabilistic model of 3D human pose** from 3D mocap data



2D landmarks



probabilistic
3D pose model

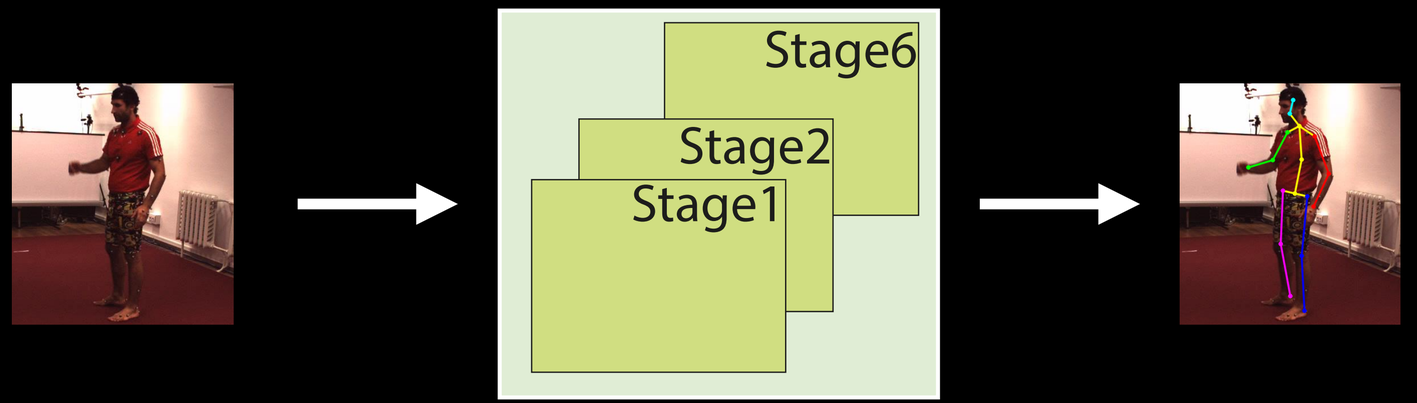


3D pose

This model lifts 2D joint positions (**landmarks**) into 3D

Our approach

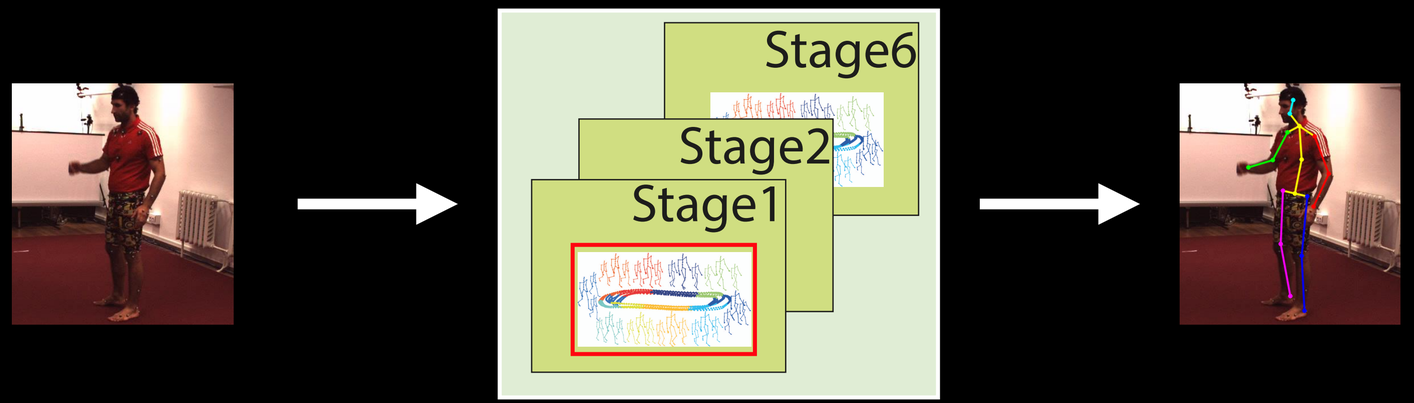
- Next, we train a novel end-to-end multi-stage CNN for 2D landmark estimation



Multi-stage CNN

Our approach

- Next, we train a novel end-to-end multi-stage CNN for 2D landmark estimation



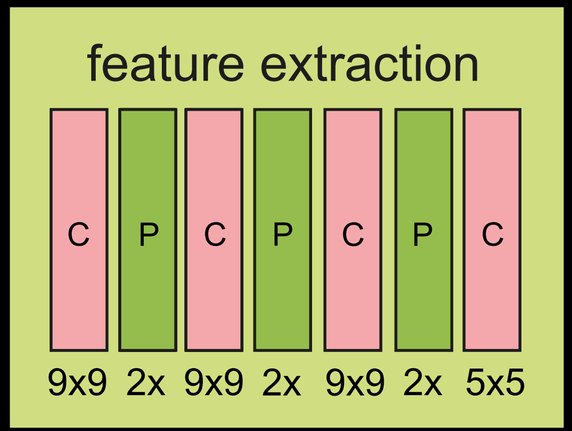
- Each stage includes a new layer based on our **probabilistic 3D pose model** of human poses to enforce 3D pose constraints

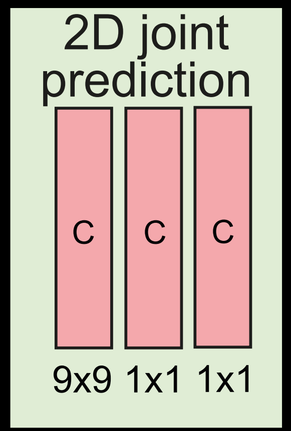
Detailed architecture

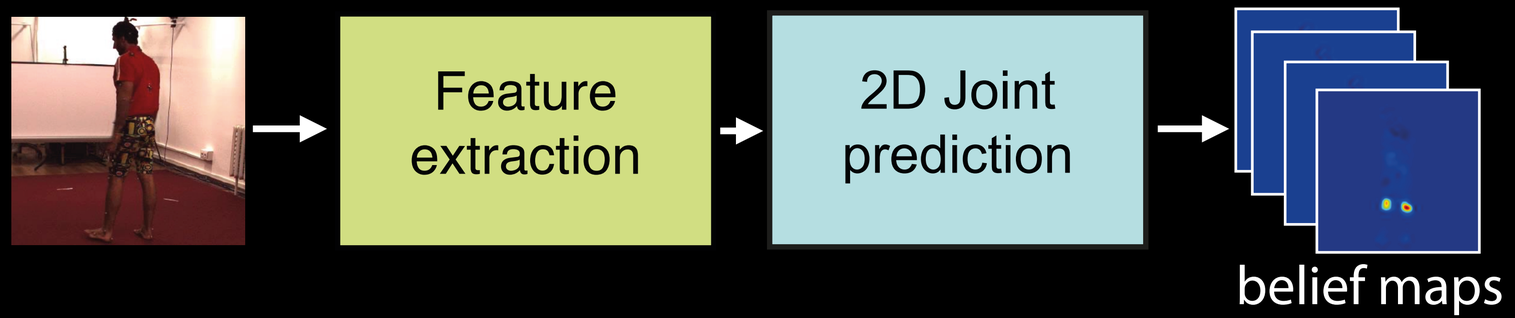
Feature extraction

2D Joint prediction

Convolutional layers





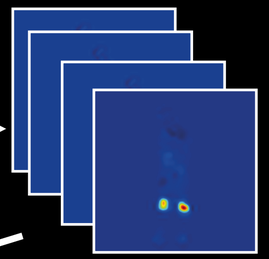


For each landmark, a **2D belief map** is generated

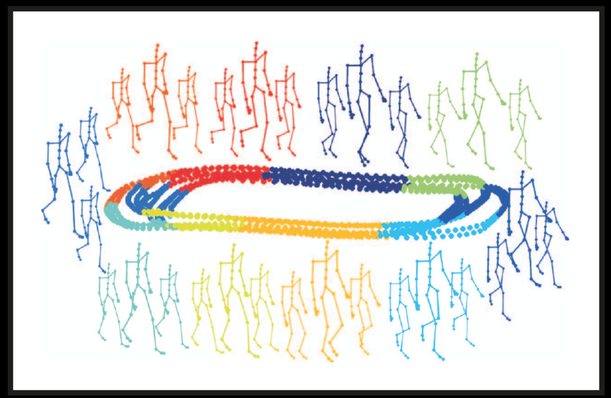
This defines how confident the architecture is that a specific landmark occurs at any given pixel *(u,v)* of the input image

Feature extraction

2D Joint prediction



belief maps



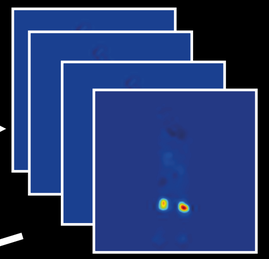
Probabilistic 3D pose model

3D pose

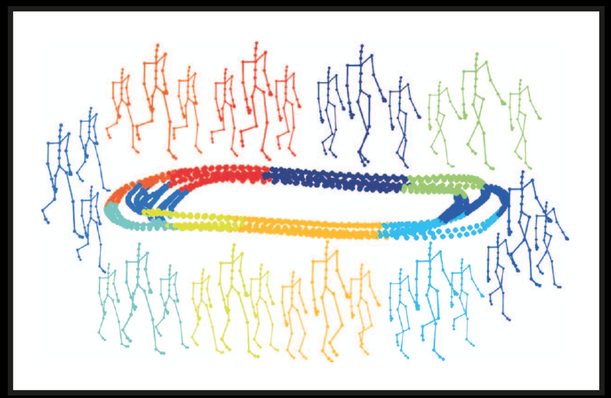
Our pre-learned probabilistic model **lifts 2D landmarks into 3D** and injects 3D pose information

Feature extraction

2D Joint prediction



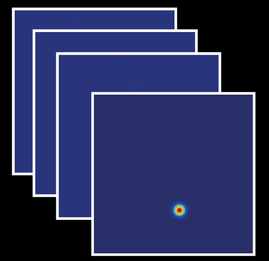
belief maps



Probabilistic 3D pose model

3D pose

belief maps



The 3D pose is used to generate a new set of **2D belief maps**

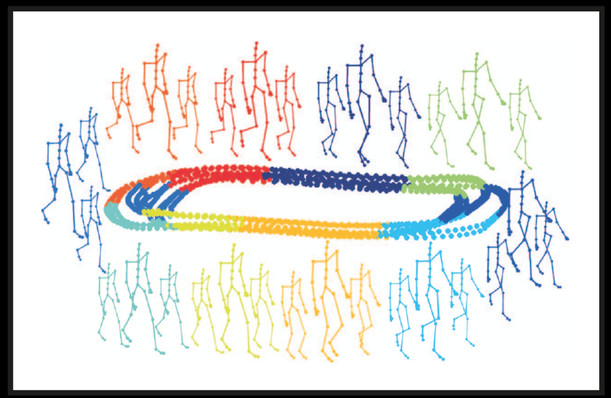
Feature extraction

2D Joint prediction

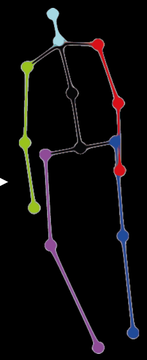
belief maps

Belief maps are **fused** together

2D FUSION

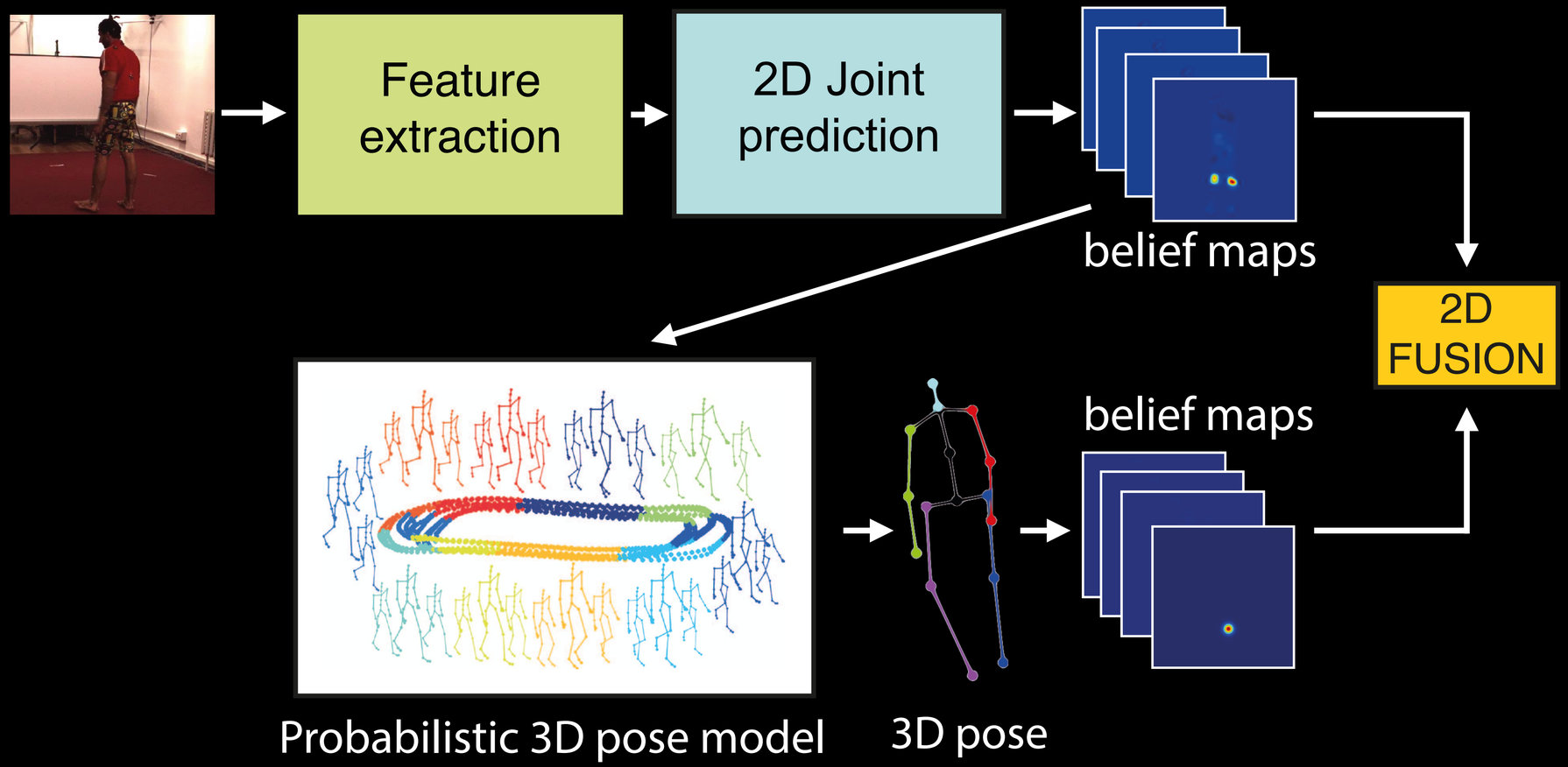


Probabilistic 3D pose model



3D pose

belief maps


Feature extraction
2D Joint prediction
belief maps
2D FUSION
belief maps
Probabilistic 3D pose model
3D pose

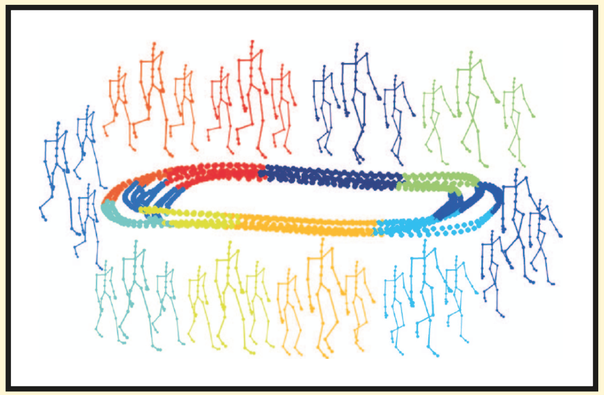
Feature extraction

2D Joint prediction

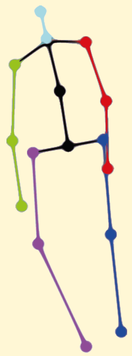
belief maps

2D FUSION

belief maps



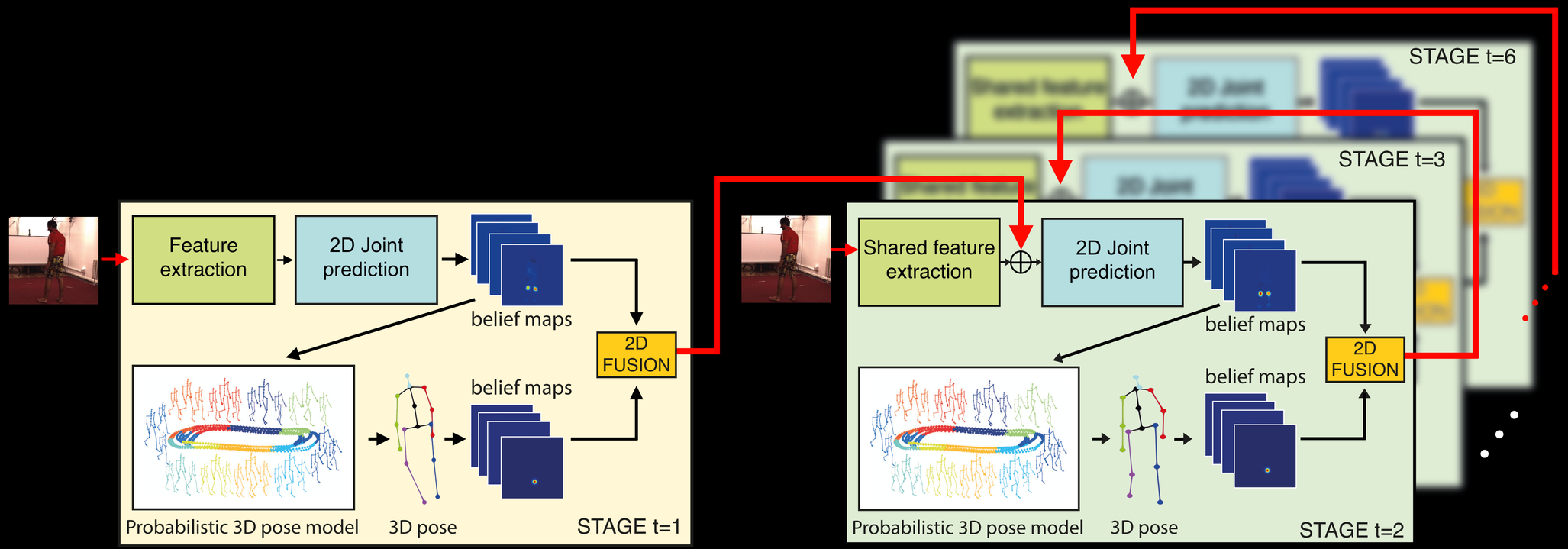
Probabilistic 3D pose model



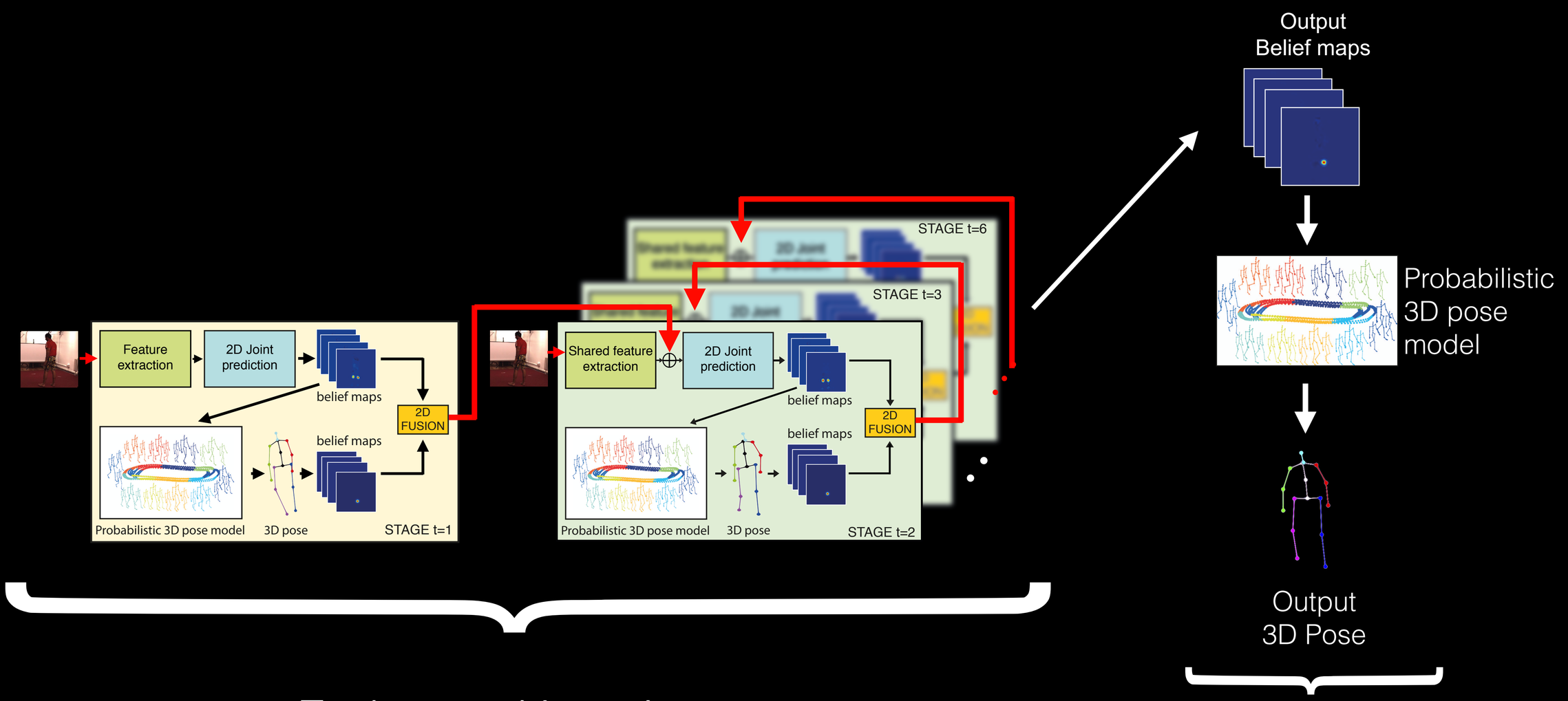
3D pose

STAGE t=1

The **2D belief maps** from each stage are used as input to the next **stage**



The accuracy of the belief maps **increases progressively** through the stages


Feature extraction
2D Joint prediction
belief maps
2D FUSION
belief maps
Probabilistic 3D pose model
3D pose
STAGE t=1
STAGE t=3
STAGE t=6
Shared feature extraction
2D Joint prediction
belief maps
2D FUSION
belief maps
Probabilistic 3D pose model
3D pose
STAGE t=2
End-to-end learning
Output
Belief maps
Probabilistic
3D pose
model
Output
3D Pose
Final lifting

Our approach achieves state-of-the-art results on the Human3.6M dataset

	Directions	Discussion	Eating	Greeting	Phoning	Photo	Posing	Purchases
LinKDE [14]	132.71	183.55	132.37	164.39	162.12	205.94	150.61	171.31
Li *et al.* [19]	-	136.88	96.94	124.74	-	168.68	-	-
Tekin *et al.* [32]	102.39	158.52	87.95	126.83	118.37	185.02	114.69	107.61
Tekin *et al.* [31]	-	129.06	91.43	121.68	-	162.17	-	-
Zhou *et al.* [44]	87.36	109.31	87.05	103.16	116.18	143.32	106.88	99.78
Sanzari *et al.* [27]	**48.82**	**56.31**	95.98	**84.78**	96.47	**105.58**	**66.30**	107.41
Ours - Single PPCA Model	68.55	78.27	77.22	89.05	91.63	110.05	74.92	83.71
Ours - Mixture PPCA Model	64.98	73.47	**76.82**	86.43	**86.28**	110.67	68.93	**74.79**

	Sitting	Sitting Down	Smoking	Waiting	Walk Dog	Walking	Walk Together	Average
LinKDE [14]	151.57	243.03	162.14	170.69	177.13	96.60	127.88	162.14
Li *et al.* [19]	-	-	-	-	132.17	69.97	-	-
Tekin *et al.* [32]	136.15	205.65	118.21	146.66	128.11	65.86	77.21	125.28
Tekin *et al.* [31]	-	-	-	-	130.53	**65.75**	-	-
Zhou *et al.* [44]	124.52	199.23	107.42	118.09	114.23	79.39	97.70	113.01
Sanzari *et al.* [27]	116.89	**129.63**	97.84	**65.94**	130.46	92.58	102.21	93.15
Ours - Single PPCA Model	115.94	185.72	88.25	88.73	92.37	76.48	77.95	92.96
Ours - Mixture PPCA Model	**110.19**	173.91	**84.95**	85.78	**86.26**	71.36	**73.14**	**88.39**

Example results on the Human3.6M dataset