2025 Spring 3D CV HW3

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1 Human pose estimation

SMPLify is a method for estimating human body pose and shape from images. It uses a statistical model of the human body, represented by the SMPL model, to fit a 3D mesh to 2D key points detected in the image. The algorithm works by minimizing the difference between the projected 3D mesh and the detected 2D key points, while also enforcing priors on the pose and shape of the body. As well as checking for interpenetration of the mesh with itself. The algorithm consists of the steps outlined in Figure 1. Only the first image in the dataset is used to demonstrate the output of SMPLify.

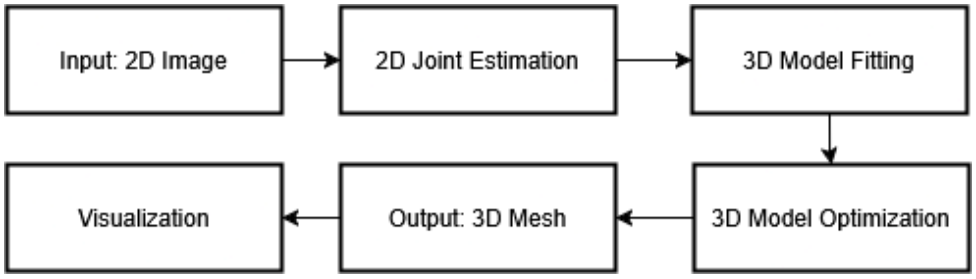
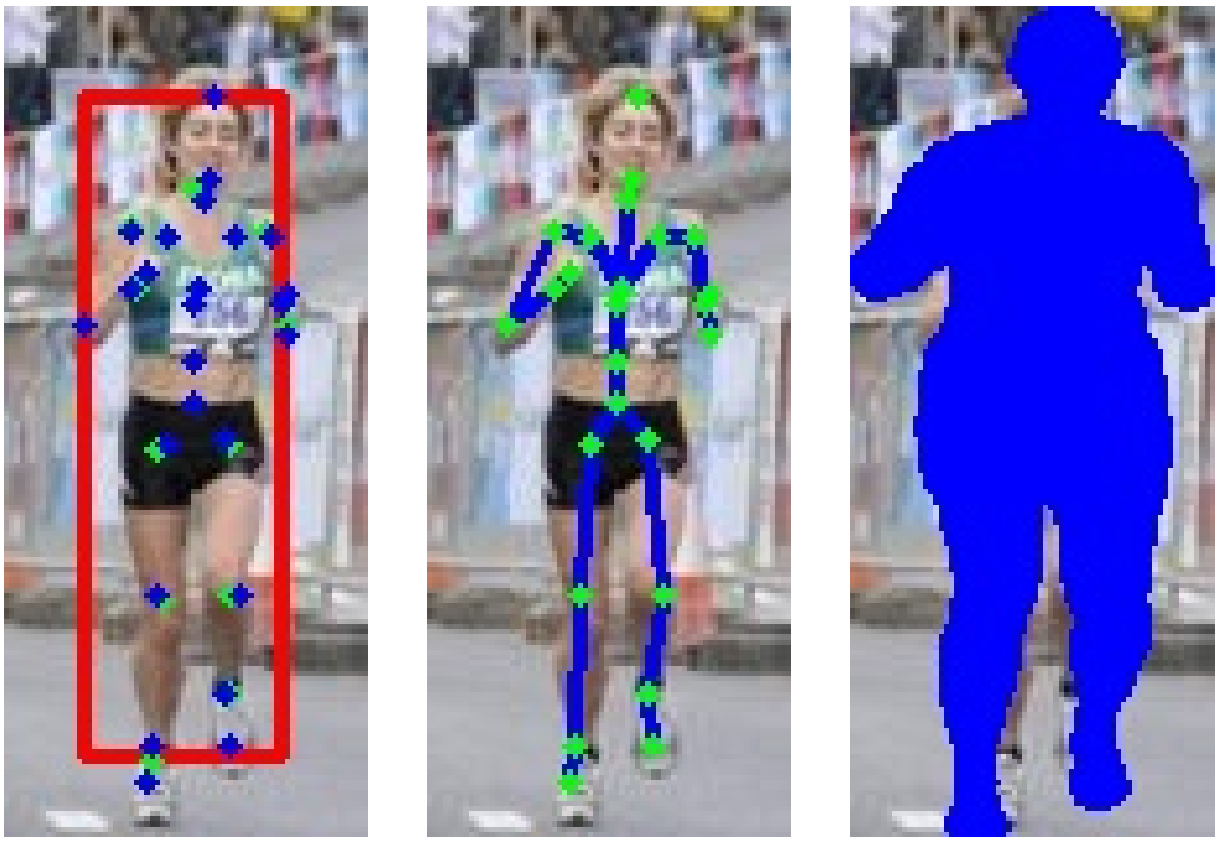


Figure 1: Pipeline of the SMPLify algorithm.

In total there are 14 key points in the ground truth data. Meanwhile the output SMPL model has 24 key points. This is somewhat visible in Figure 2a where the bounding box and key points are shown. Ground truth is in green and the SMPL model key points are in blue. Around the spine only SMPL key points are seen. Due to the ground truth data not having a key points for the spine.

The unconnected key point in the skeleton is the head as seen in Figure 2b. Which is being inserted by the code itself and therefore not linked to the SMPL model.



(a) Bounding box and key points (b) Skeleton (c) Projected mesh

Figure 2: Visualizations of the SMPLify output

The OBJ file format is a simple data format that represents 3D geometry. It consists of various elements such as vertices, texture coordinates and faces. Each line in the file starts with a keyword that indicates the type of data it contains. For example, lines starting with "v" represent vertices and "f" for faces. Following that is the data for that element, such as the coordinates of the vertex or the indices of the vertices that make up a face. To store triangular meshes, the OBJ format uses faces defined by three vertices, which are specified by their indices in the vertex list.

The resulting OBJ can then be displayed in MeshLab as in Figure 3.

Figure 3: Image of the exported mesh.

2 Prior Analysis

The SMPLify algorithm uses several priors to ensure that the estimated human body pose and shape are realistic and physically plausible. The priors are pose, shape, and interpenetration. The pose prior is used to constrain the estimated pose of the body to be within a realistic range of human motion. Pose prior is calculated around the joints to evaluate if they are violating natural constraints of human motion, such as the range of motion of the joints. The shape prior is used to constrain the estimated shape of the body to be within a realistic range of human body shapes. The shape prior is based on a statistical model of human body shapes, which is learned from a large dataset of 3D scans of human bodies. The interpenetration prior is used to ensure that the estimated 3D mesh does not intersect with itself, which would be physically impossible. Capsules around the mesh are used to check for interpenetration. Instead of checking every triangle for intersection, which would be computationally expensive, the algorithm checks if the capsules around the mesh intersect with each other.
The reconstruction error is calculated by taking the mean Euclidean distance between corresponding joints. It does not take into account the shape of the mesh, only the position of the joints.
The reconstruction error with all priors is 5.1964.

Default weights:

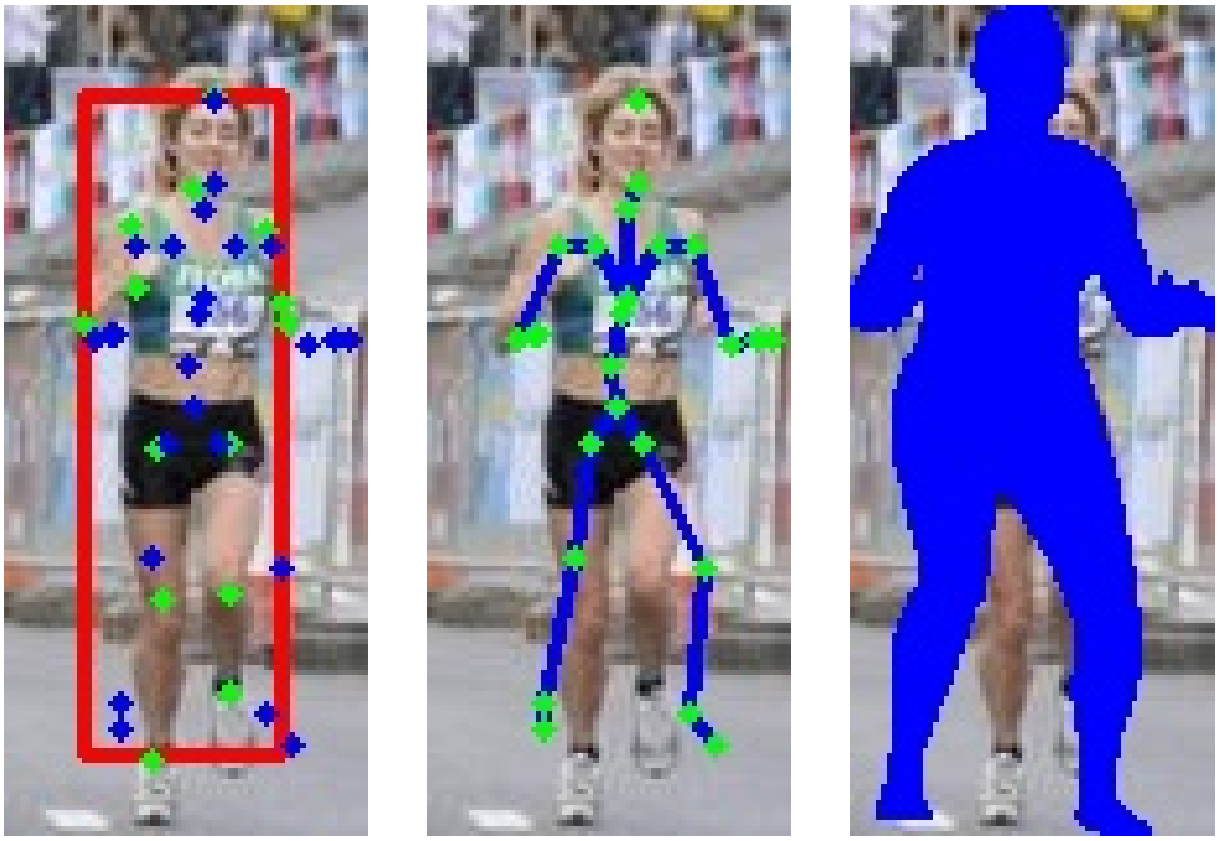
1. Pose: [404, 404, 57.4, 4.78]
2. Shape: [100, 50, 10, 5]

Adjusted weights:

1. Pose: [30, 250, 2, 400]
2. Shape: [66, 12, 5, 98]

Reconstruction error with adjusted weights is 9.2056. Which is higher than the reconstruction error with the default weights.

The errors are very visible in the visualizations with adjusted weights in Figure 4. The key points are not aligned due to the overall pose being off. This is very visible in the skeleton in Figure 4b. Therefore the mesh is also inaccurate, due to it spanning the skeleton.



(a) Bounding box and key points (b) Skeleton (c) Projected mesh

Figure 4: Visualizations with adjusted weights

2.1 No pose prior

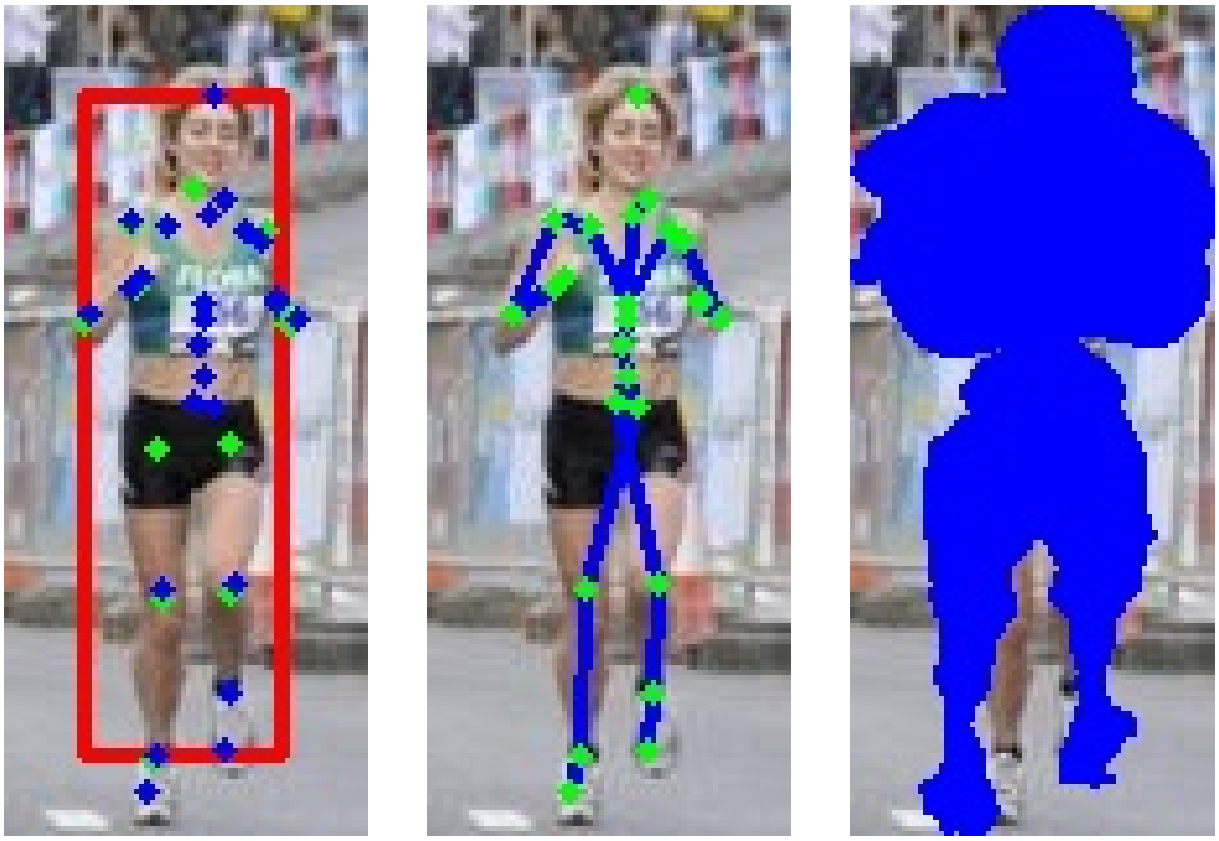
Without the pose prior, the reconstruction error is 5.4567. The problem which arises when disabling the pose prior is that joints end up in physically impossible positions.

(a) Bounding box and key points (b) Skeleton (c) Projected mesh

Figure 5: Visualizations without the pose prior

2.2 No shape prior

Without the shape prior, the reconstruction error is 6.742. The problem which arises when disabling the shape prior is that the mesh does not fit the body shape. This is visible in Figure 6c, where the mesh is not aligned with the body shape.

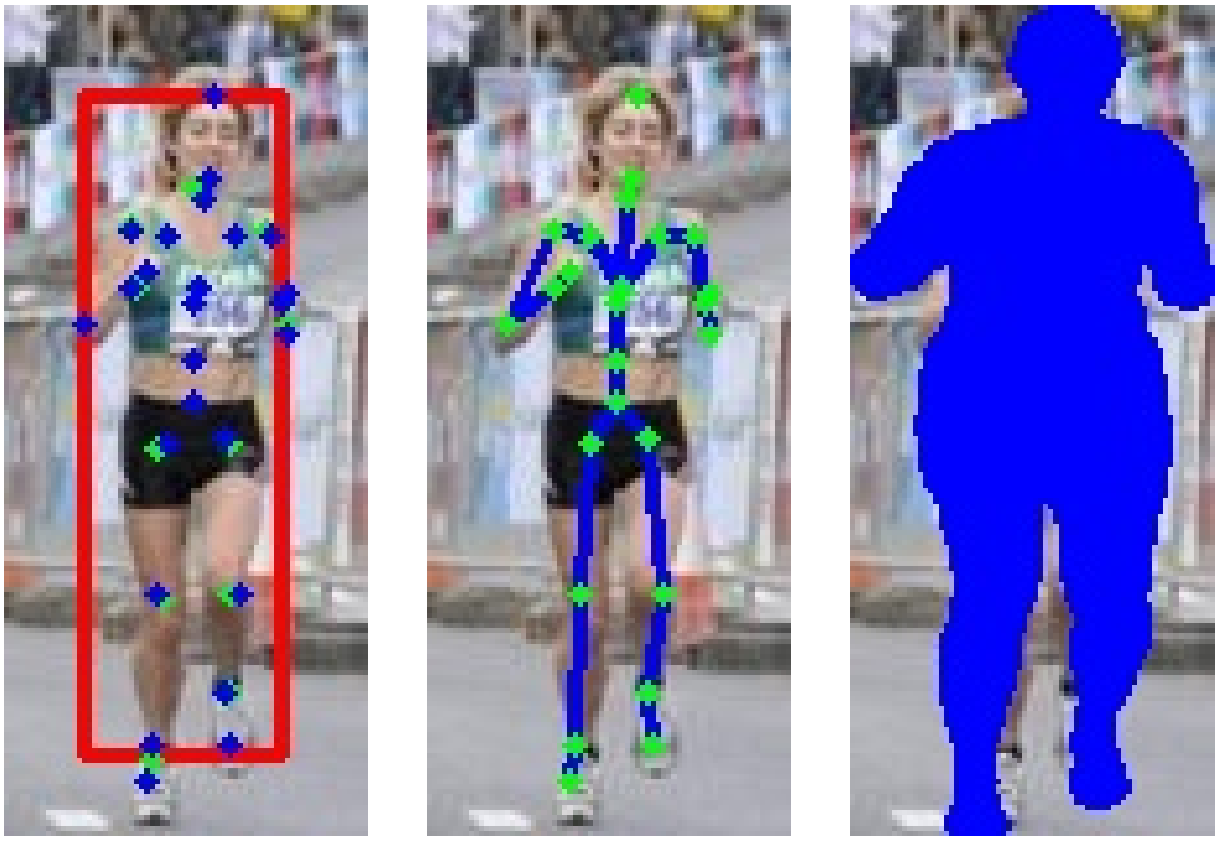


(a) Bounding box and key points (b) Skeleton (c) Projected mesh

Figure 6: Visualizations without the shape prior

2.3 No interpenetration prior

Without the interpenetration prior, the reconstruction error is 5.1931. The problem which arises when disabling the interpenetration prior is that the mesh intersects with itself. This is not very visible in Figure 7c, due to the pose not leading to many interpenetrations.



(a) Bounding box and key points (b) Skeleton (c) Projected mesh

Figure 7: Visualizations without the interpenetration prior

2.4 No priors

Without any priors, the reconstruction error is 5.1731. The problem which arises when disabling all priors is that the mesh does not fit the body shape and the joints are in physically impossible positions. Combining the problems of the previous three sections. But the reconstruction error is very slightly lower than with all the priors. This can be due to variance but also because the priors restrict how close the key points can be to the ground truth.

(a) Bounding box and key points (b) Skeleton (c) Projected mesh

Figure 8: Visualizations without any priors

2.5 Prior importance

The prior which is most important for SMPLify is the shape prior. This is shown by the fact that without it the reconstruction error is significantly higher than with the other priors. Meanwhile the least important is the interpenetration prior. Due to it only being important when the shape is correct.

Excluded prior	Reconstruction error	Importance
Shape	6.742	1st
Pose	5.4567	2nd
Interpenetration	5.1931	3rd
All	5.1731	NULL

Table 1: Table to test captions and labels.