Part-based modelling of compound scenes from images

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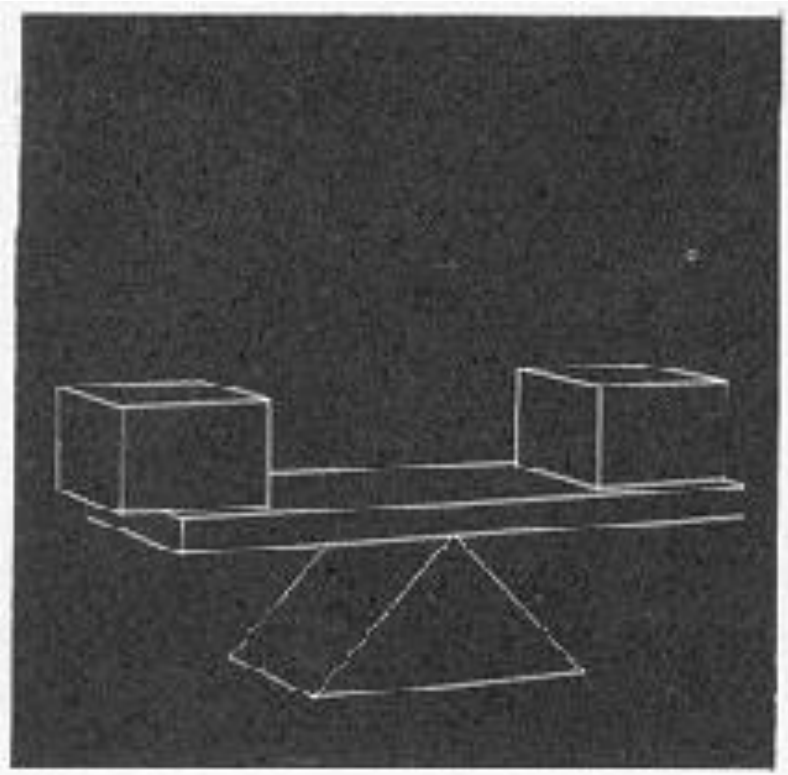
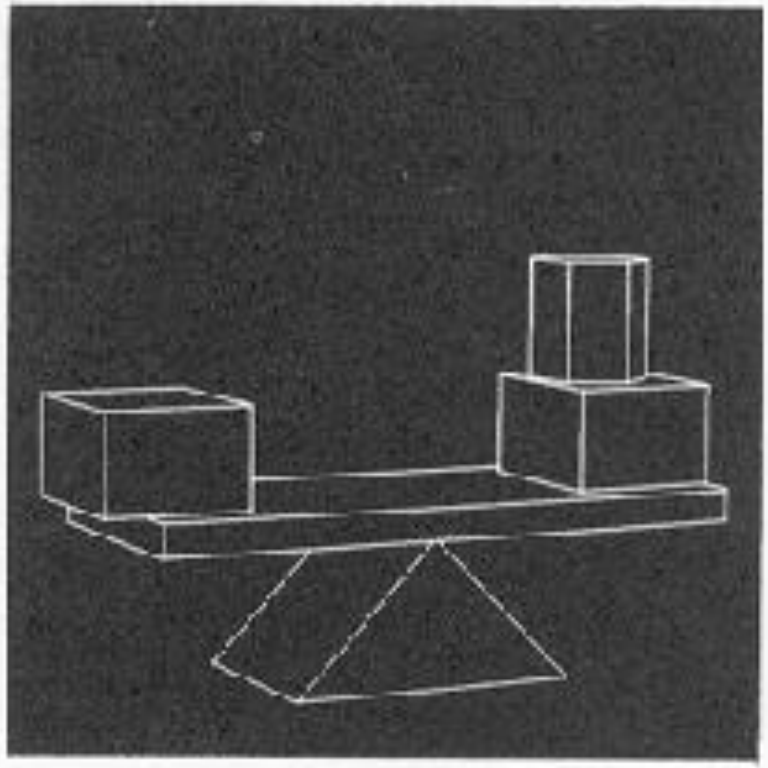
Deconstruction has been a theme

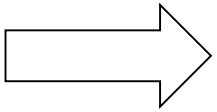


(e) See-saw.



(f) With hexagonal prism.

Structure and semantics interact

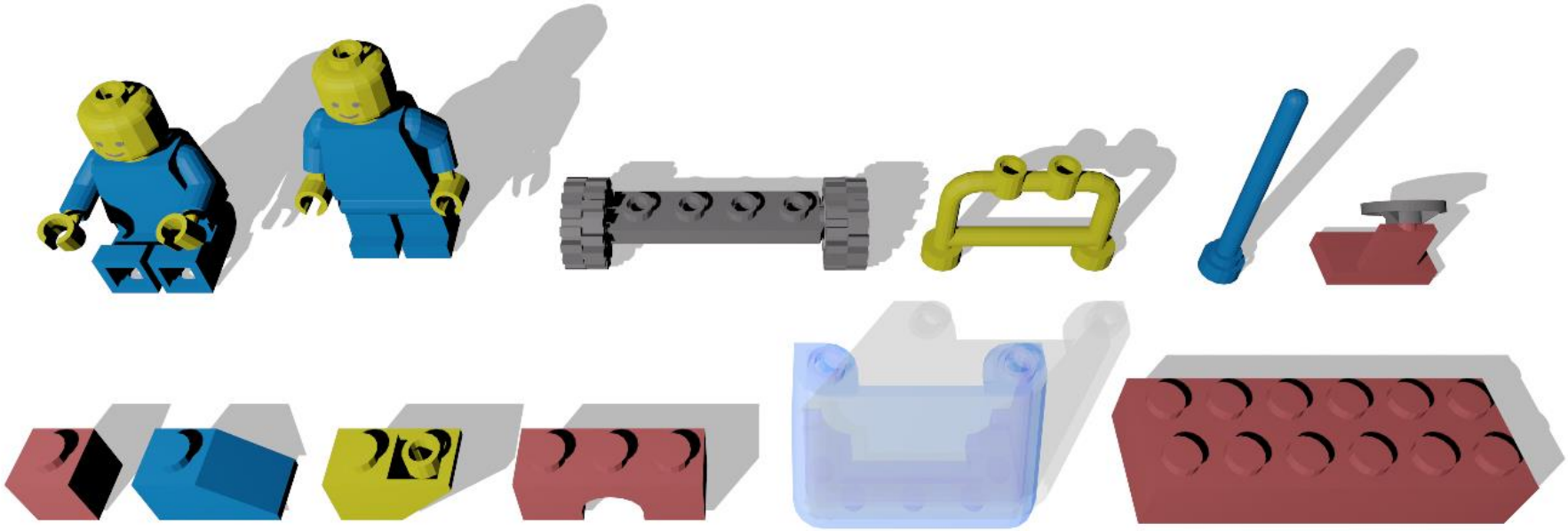


Structure and semantics interact

Deconstruction

- We want to be able to take the world apart
  - And put it back together
- We want to reason about the solution in 3D
  - Not least so we can ensure the solution makes sense
- We need a set of parts to build our models from

Lego!

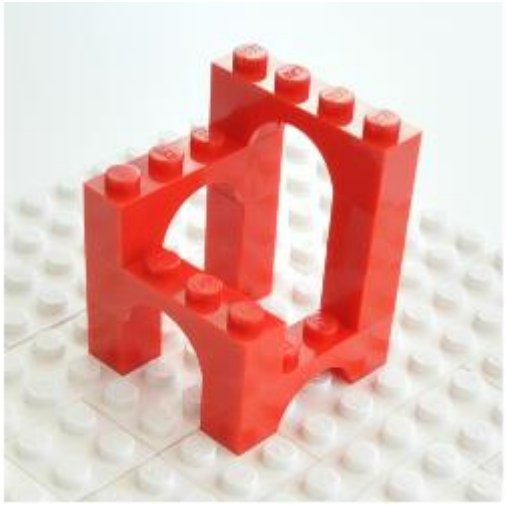


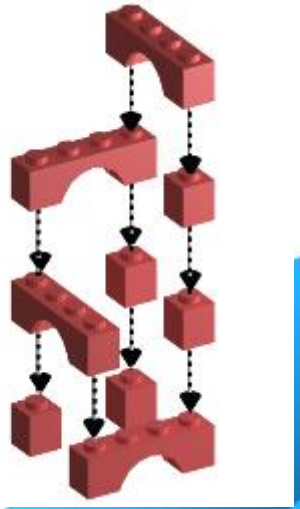
Silhouette-based composition

- We're only interested in shape

- Silhouettes can be composed linearly

Deconstruction



- Render all possible building blocks in every possible position, and record the silhouette of each
- Then reconstruct object silhouettes as combinations of these block silhouettes

Template shapes

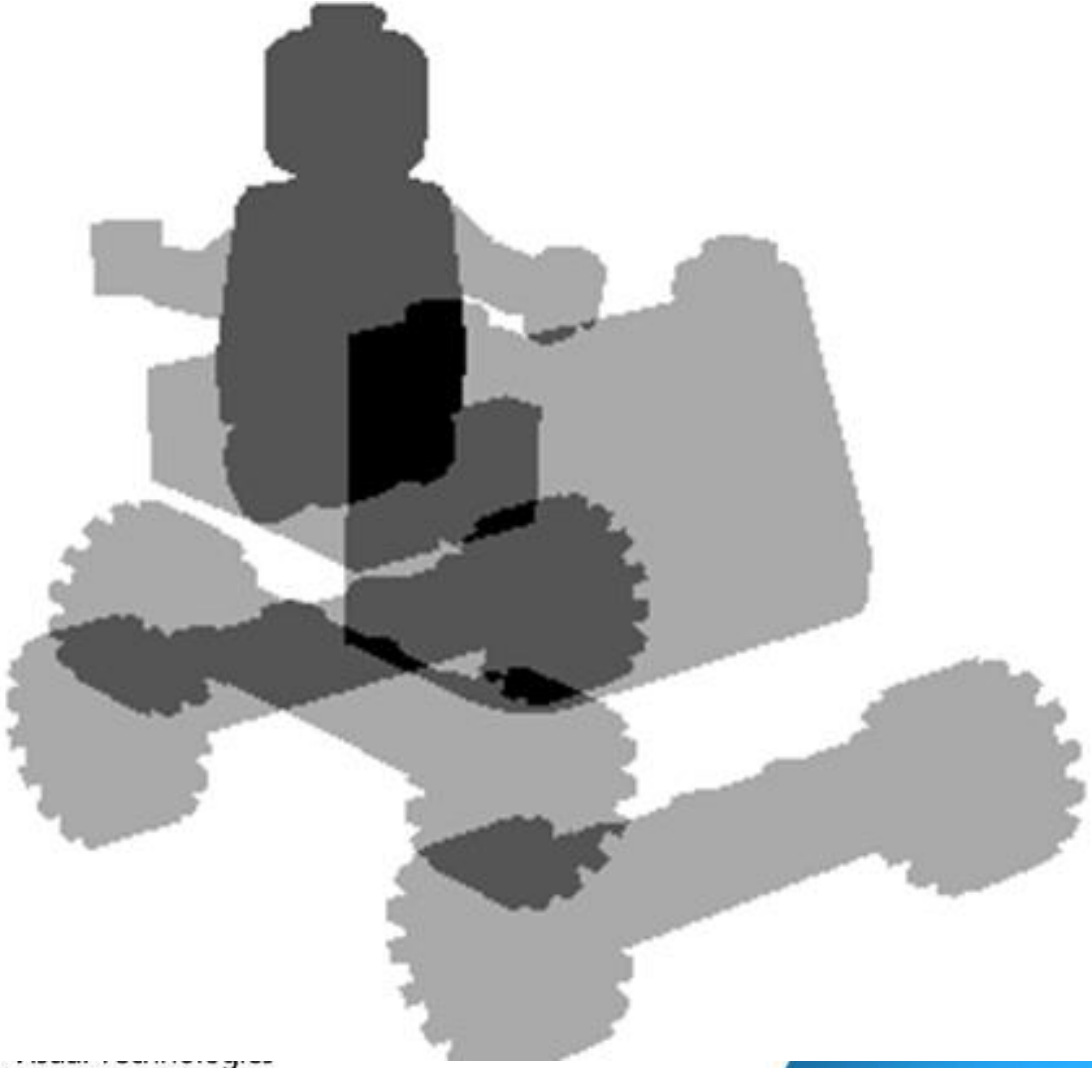
- nTemplates = nShapes x nPositions x nRotations
  - So there are lots of them
  - But they are sparsely used

A linear model of composition

$$\arg\min_{\boldsymbol{\alpha}\in\Omega} \|\mathbf{y} - \boldsymbol{\Pi}\boldsymbol{\alpha}\|_1 + \lambda\|\boldsymbol{\alpha}\|_1$$

- $\mathbf{y}$ the silhouette of the shape to be recovered
- $\boldsymbol{\Pi}\boldsymbol{\alpha}$ the reconstructed silhouette
  - $\boldsymbol{\alpha}$ a binary vector of block coefficients
  - $\boldsymbol{\Pi}$ a matrix with one block silhouette per column
- Ω the set of plausible models
- λ a scale factor controlling parsimony

Composition problems



A better model of composition

- Separate foreground from background (rows)
  - $\mathbf{y} \rightarrow \mathbf{y}_0, \mathbf{y}_1$ and $\mathbf{\Pi} \rightarrow \mathbf{\Pi}_0, \mathbf{\Pi}_1$
- Add slack variables for foreground

$$\arg\min_{\boldsymbol{\alpha}\in\Omega,\boldsymbol{\xi}} \|\mathbf{\Pi}_0\boldsymbol{\alpha}\|_1 + \|\boldsymbol{\xi}\|_1 + \lambda\|\boldsymbol{\alpha}\|_1$$
$$\text{s.t. } \mathbf{y}_1 - \mathbf{\Pi}_1\boldsymbol{\alpha} \leq \boldsymbol{\xi},\ 0 \leq \boldsymbol{\xi} \leq 1$$

Constraints - Intersection

- Form matrix $\mathbf{\Gamma}$ where every row represents a constraint
  - If templates i and j intersect then insert a row (k) in $\mathbf{\Gamma}$ such that

$$\mathbf{\Gamma}_{ki} = 1, \mathbf{\Gamma}_{kj} = 1$$

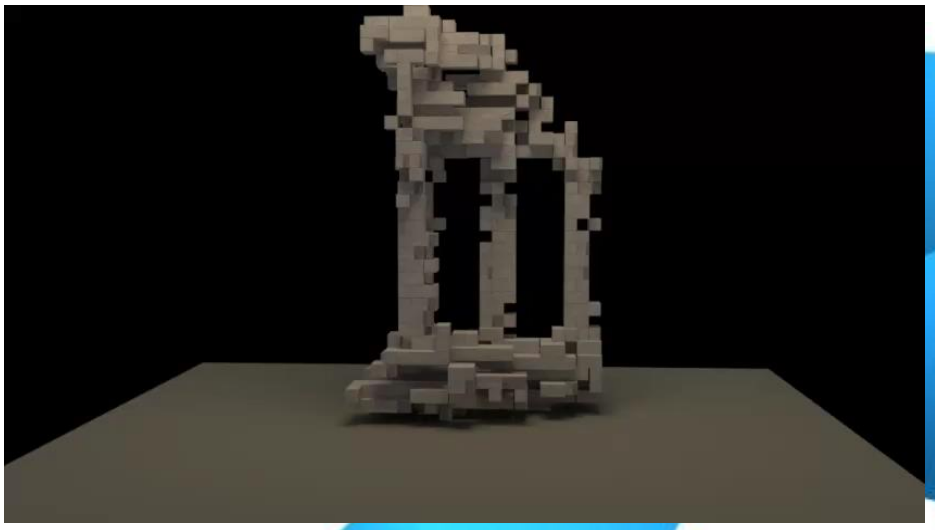
  - Insert constraint into optimisation problem that

$$\mathbf{\Gamma}\boldsymbol{\alpha} \leq \mathbf{1}$$

Constraints - Gravity

- Form Υ where every row represents a constraint
  - If template i needs support t set $\Upsilon_{ii} = t$
  - If template j provides s support to i set $\Upsilon_{ij} = -s$
- And require that

$$\Upsilon \alpha \leq 0$$



Integer programming

$$\arg\min_{\boldsymbol{\alpha}\in\mathbb{Z}_2^T,\boldsymbol{\xi}} \|\boldsymbol{\Pi}_0\boldsymbol{\alpha}\|_1 + \|\boldsymbol{\xi}\|_1 + \lambda\|\boldsymbol{\alpha}\|_1$$
$$\text{s.t. } \mathbf{y}_1 - \boldsymbol{\Pi}_1\boldsymbol{\alpha} \leq \boldsymbol{\xi},\ \boldsymbol{\Gamma}\boldsymbol{\alpha} \leq \mathbf{1},\ \boldsymbol{\Upsilon}\boldsymbol{\alpha} \leq \mathbf{0}$$

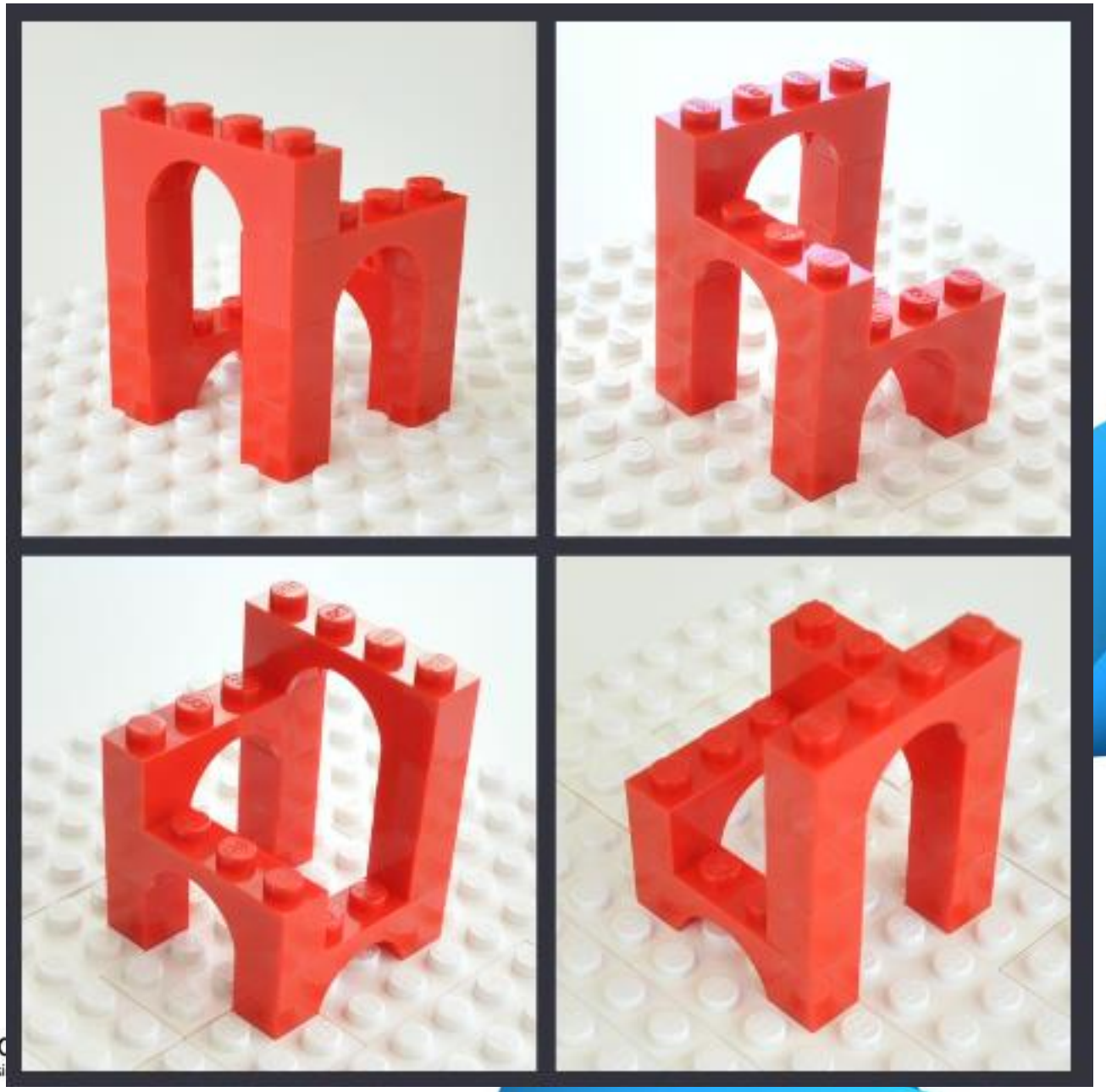
- But there are too many pixels in $\mathbf{y}_1$

Sparse recovery – Projection

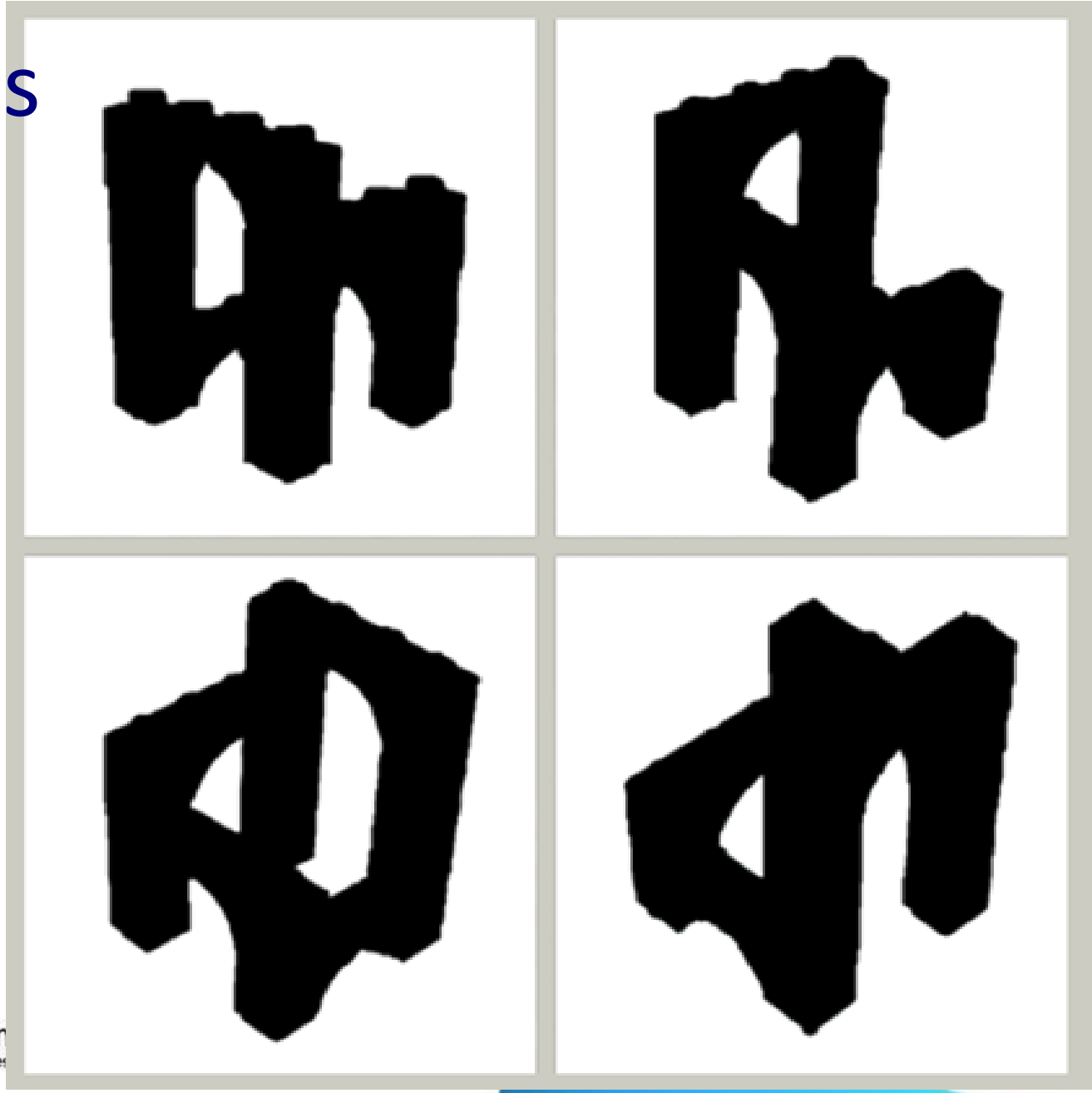
$$\arg\min_{\boldsymbol{\alpha}\in\mathbb{Z}_2^T,\boldsymbol{\xi}} \|\boldsymbol{\Pi}_0\boldsymbol{\alpha}\|_1 + \|\boldsymbol{\xi}\|_1 + \lambda\|\boldsymbol{\alpha}\|_1$$
$$\text{s.t. } \boldsymbol{\Phi}\mathbf{y}_1 - \boldsymbol{\Phi}\boldsymbol{\Pi}_1\boldsymbol{\alpha} \leq \boldsymbol{\xi},\ \boldsymbol{\Gamma}\boldsymbol{\alpha} \leq \mathbf{1},\ \boldsymbol{\Upsilon}\boldsymbol{\alpha} \leq \mathbf{0}$$

- Projection by $\boldsymbol{\Phi} \in \mathbb{R}^{D\times S}$ where D << S
- Solve the reconstruction problem in a (much) lower dimensional space

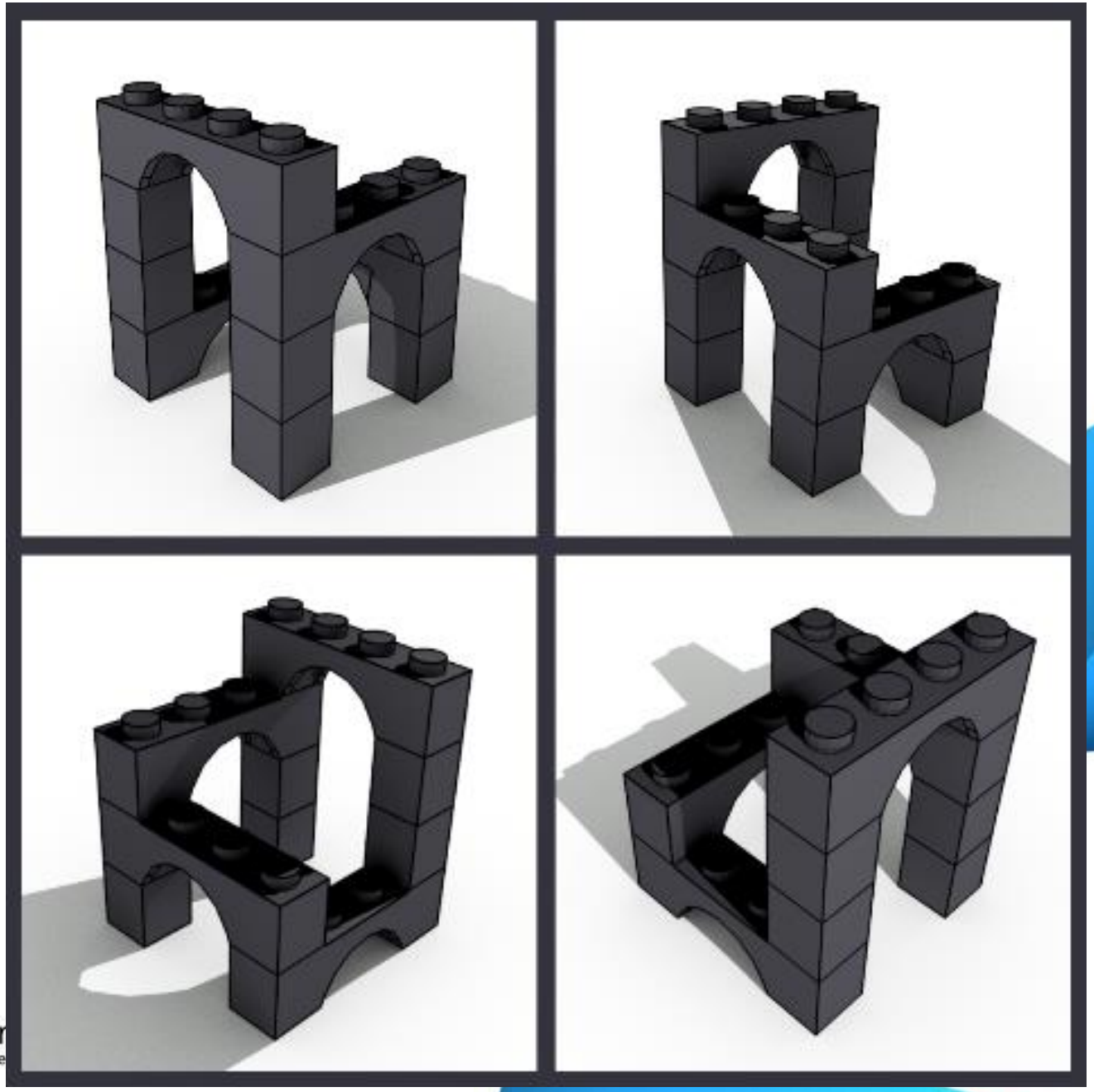
Images



Silhouettes



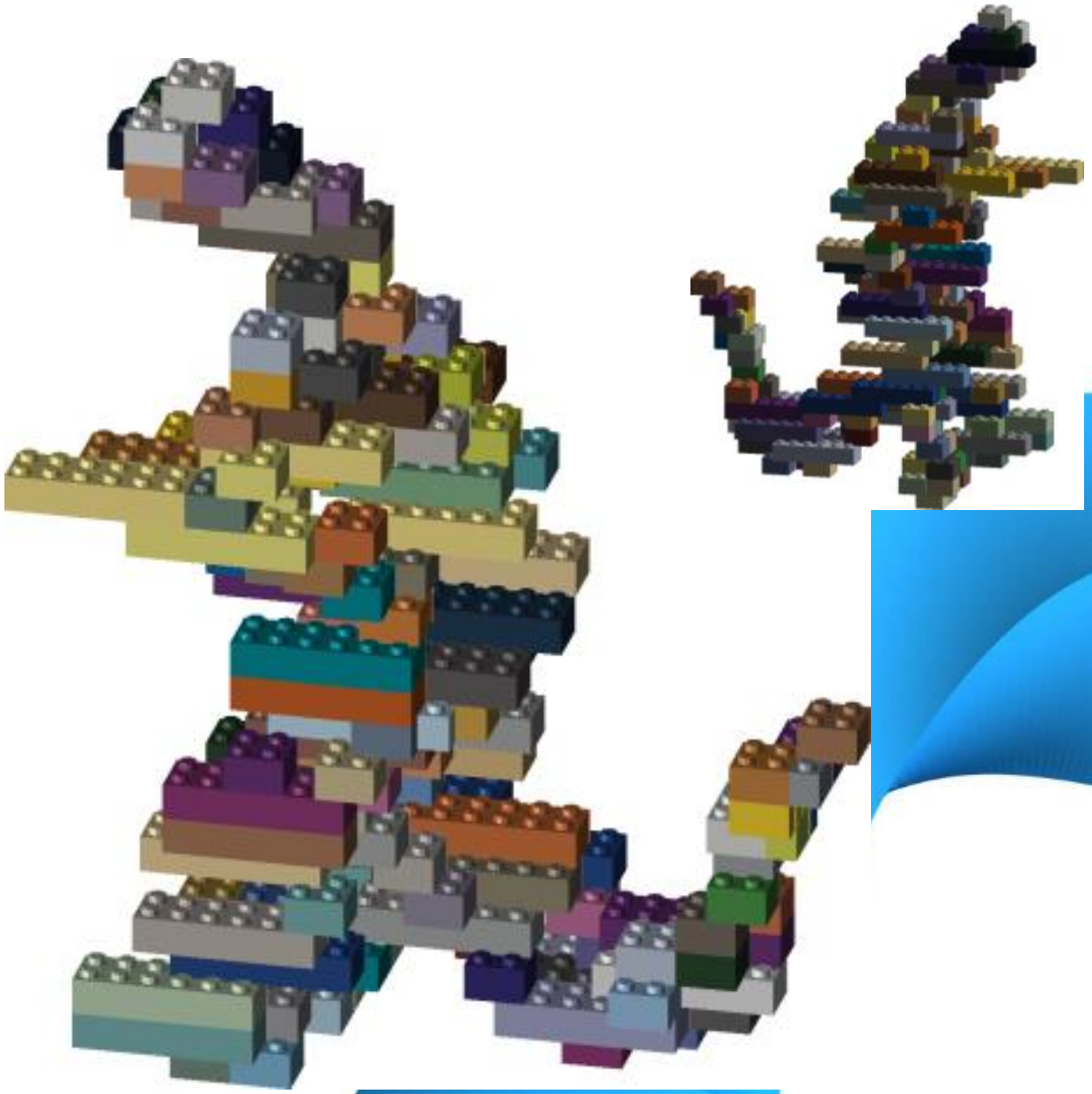
Structure



Structure

Results

Deconstructing general objects



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Deconstruction

- Part-based model
- Estimated using Integer Programming
- Incorporates physical constraints
- Reasoning in 3D
- Projected to a lower dimension without losing accuracy