Taskonomy:
Disentangling Task Transfer Learning

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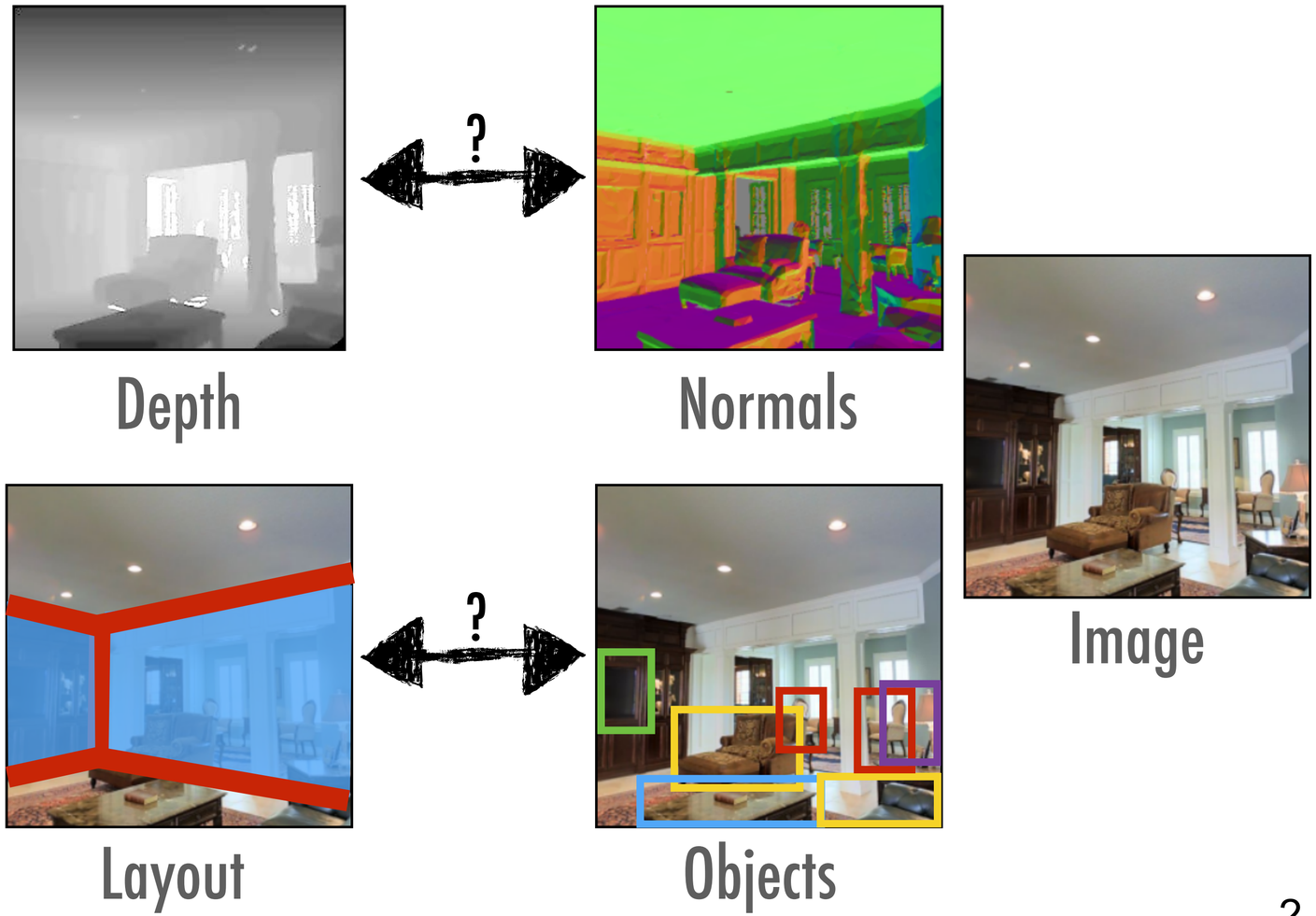
Stanford, UC Berkeley

CVPR18 [Best Paper Award]

Question: Vision problems - related or independent?



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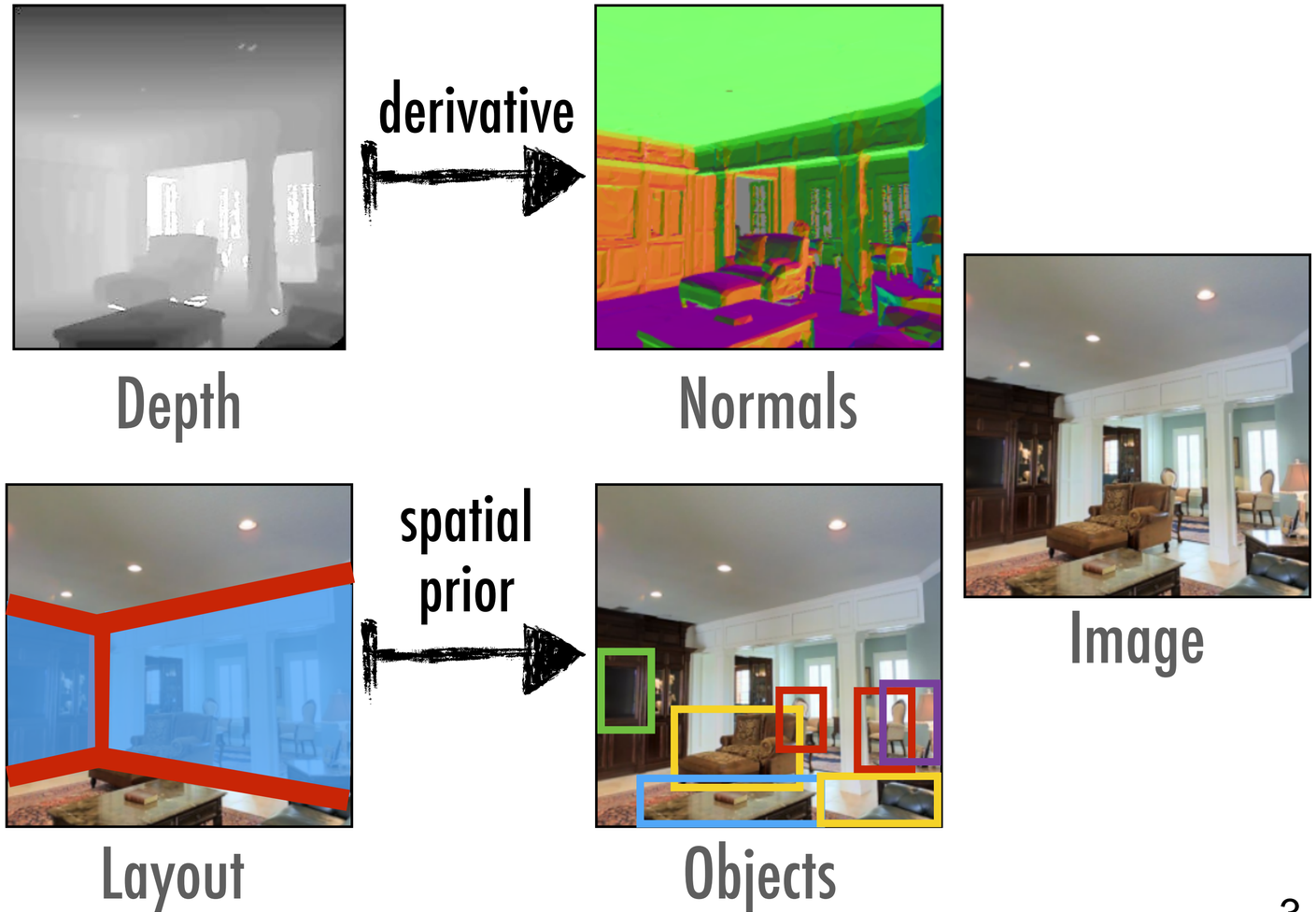
Question: Vision problems - related or independent?

- Task relationships exist
- Can be computationally measured
- Tasks belonging to a structured space
- Unified model for transfer learning



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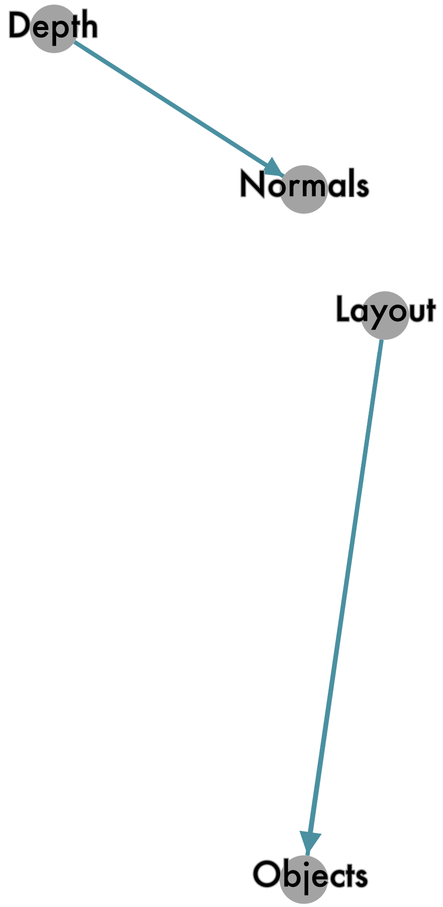
Task Relationships



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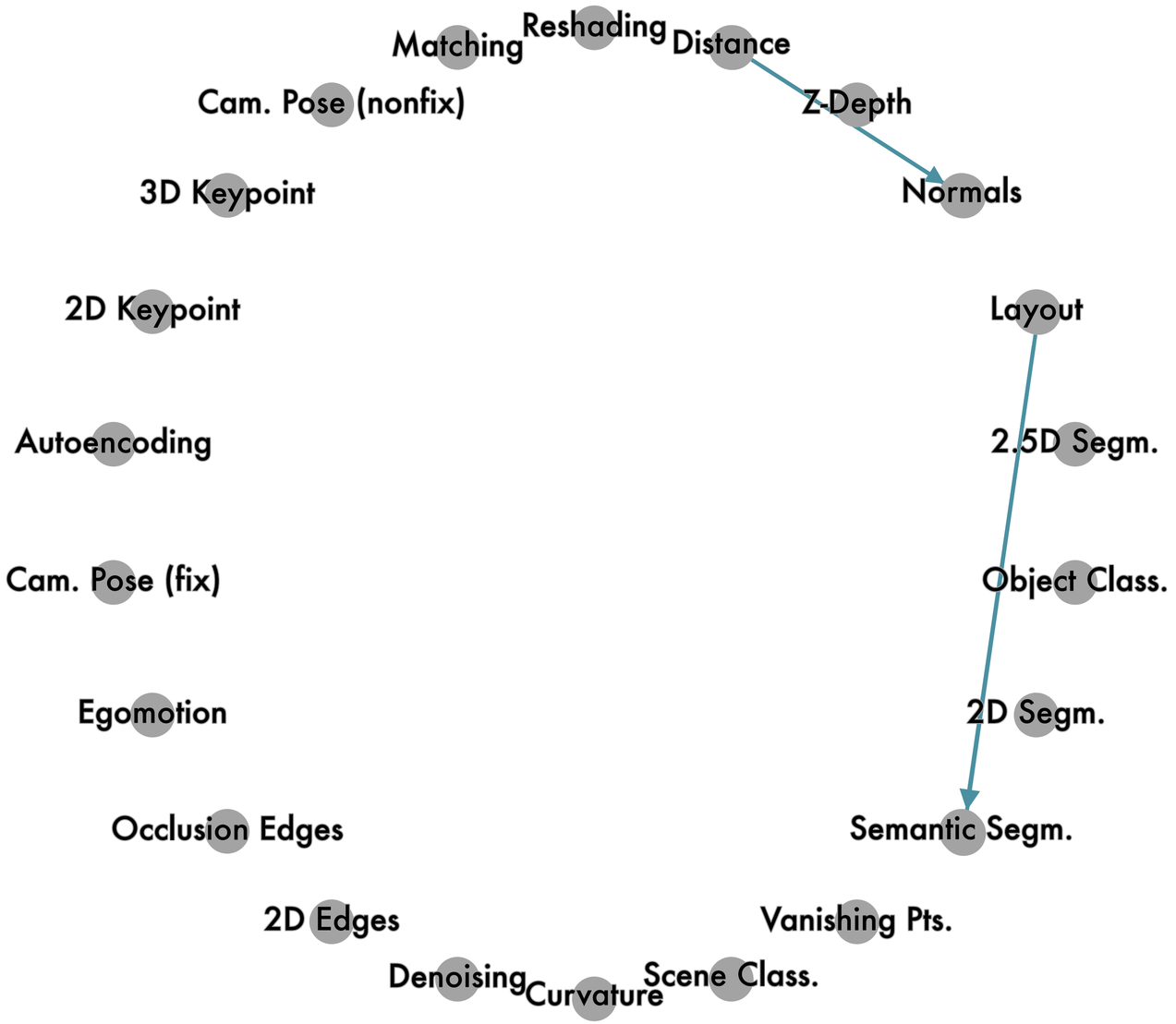
Task Relationships

Many Tasks



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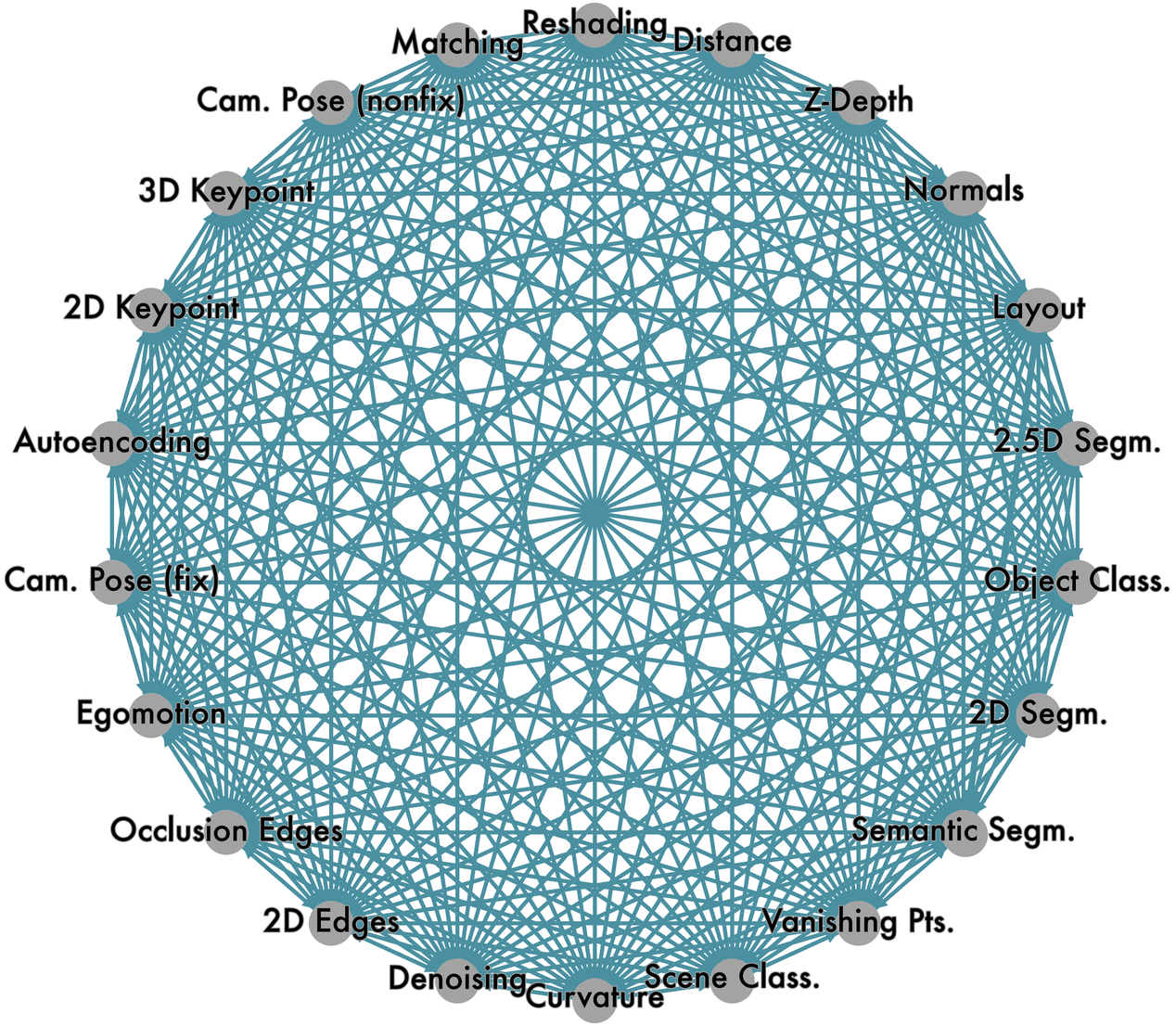
Task Relationships

Many Tasks

↓

Dense Relationships



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Task Relationships

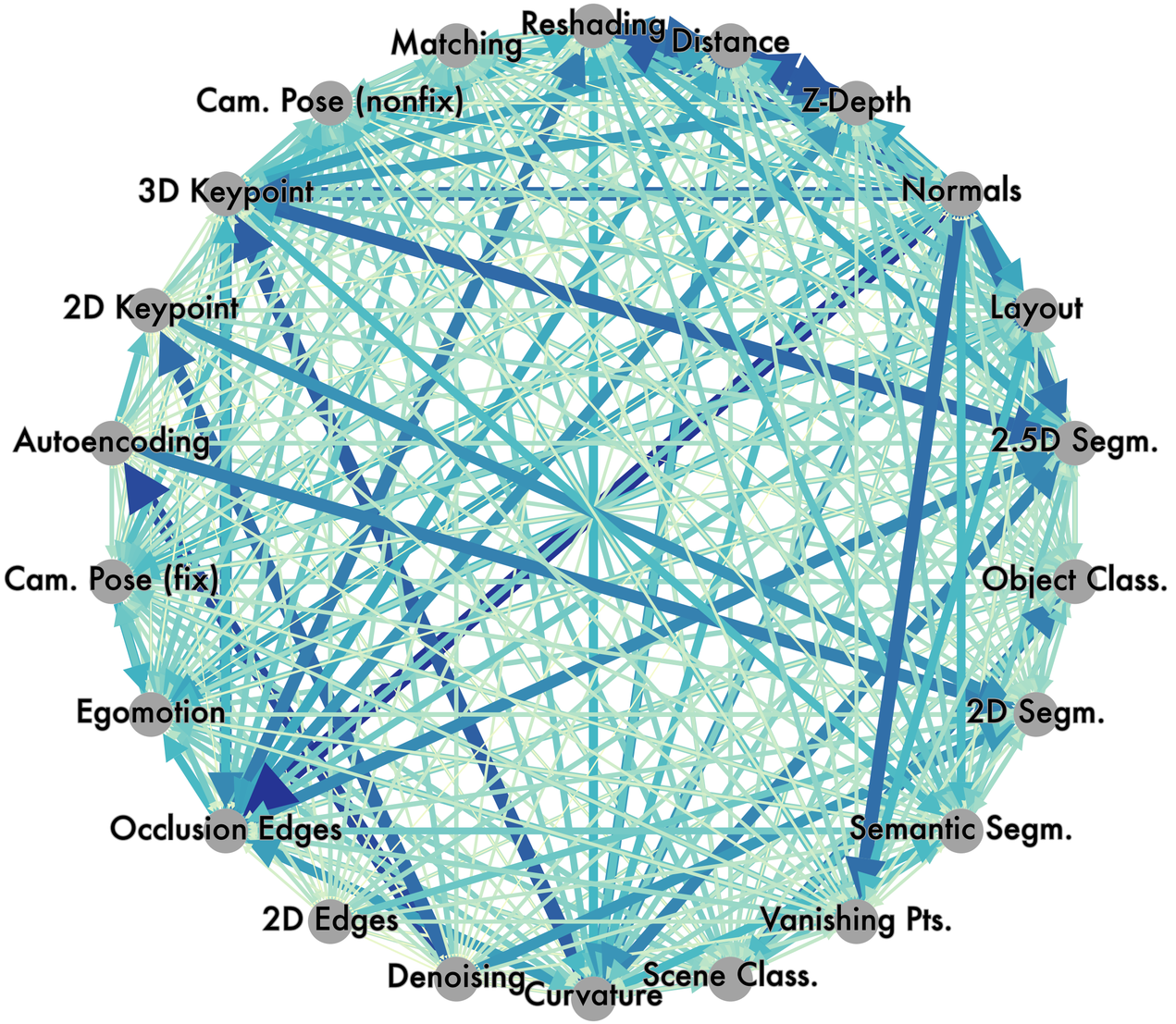
Many Tasks

↓

Dense Relationships

↓

Redundancy



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Task Relationships

Many Tasks

↓

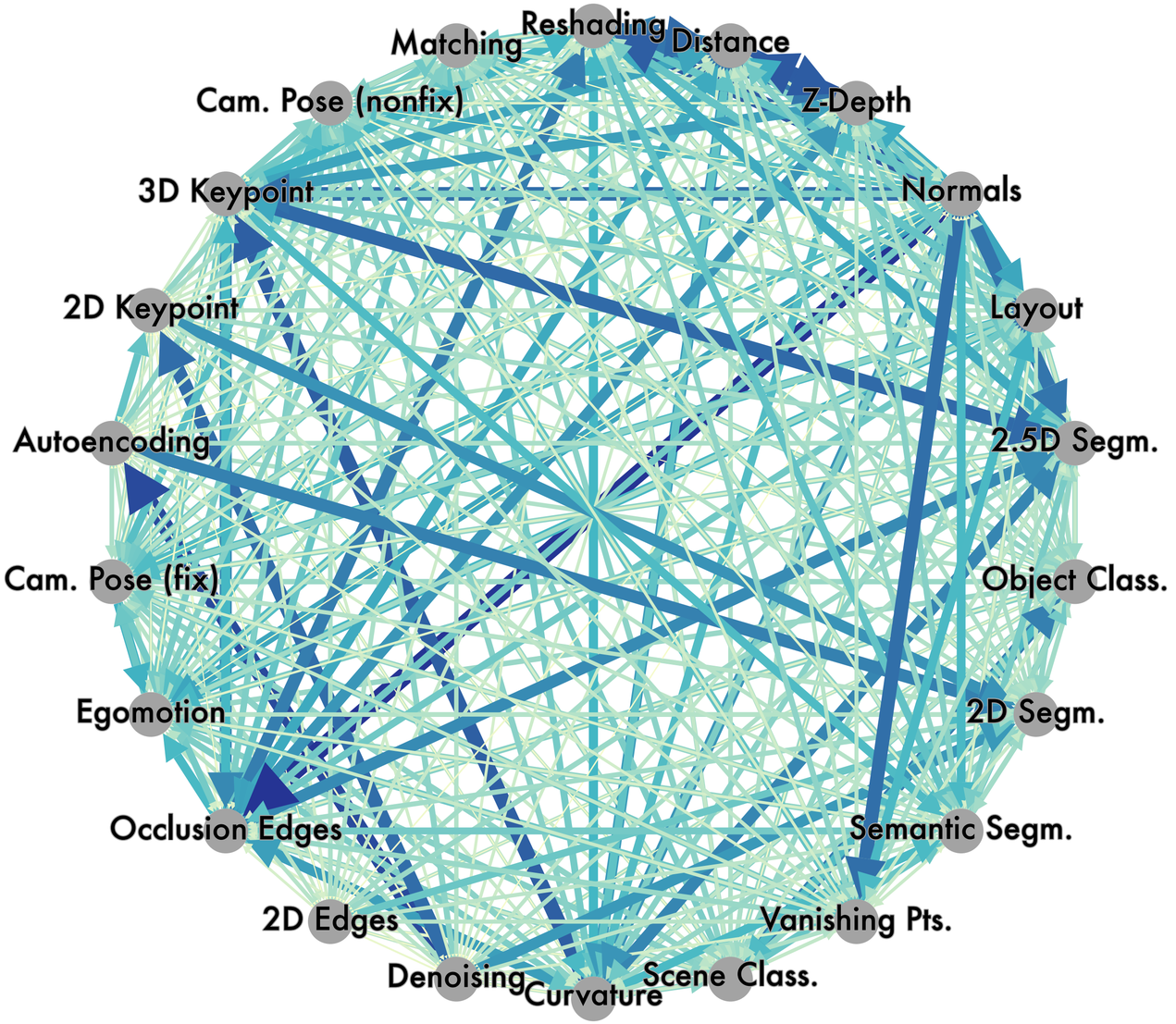
Dense Relationships

↓

Redundancy

↓

Efficiency



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Task Relationships

Many Tasks

↓

Dense Relationships

↓

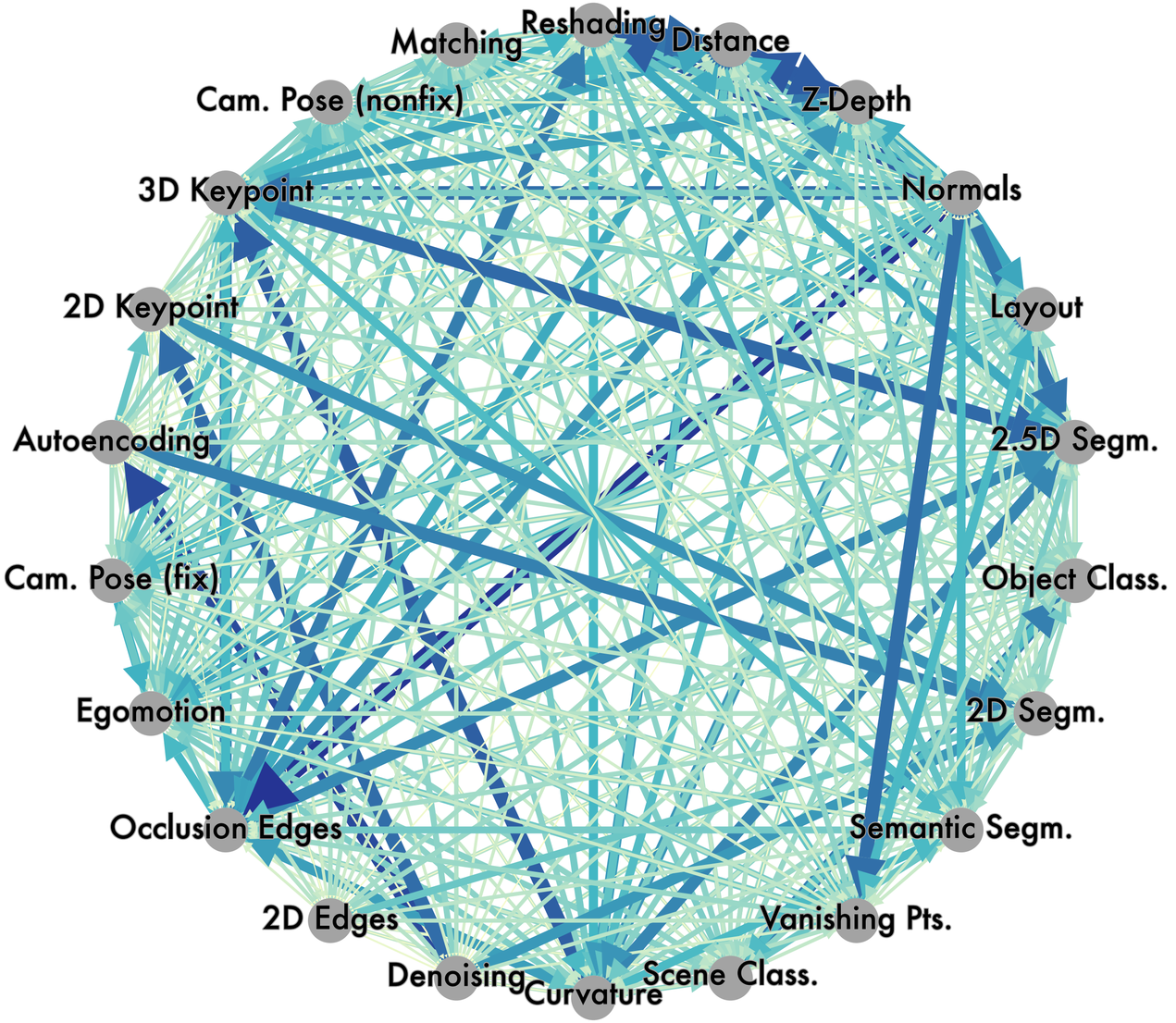
Redundancy

↓

Efficiency

Supervision
Efficiency

- Self/Un Supervised Learning [1,2,3]
- ImageNet features. "Fine-Tuning" [4,5,6]
- Meta Learning [7,8,9]
- Domain Adaptation [10,11,12]



[1] Doersch'15. [2] Noroozi'16. [3] Bengio'13. [4] Sharif'14. [5] Donahue'14. [6] Girshick'14. [7] Marcin'14. [8] Finn'16. [9] Lake'16. [10] Yang'07. [11] Saenko'10. [12] Hoffman'14.

Task Relationships

Many Tasks

↓

Dense Relationships

↓

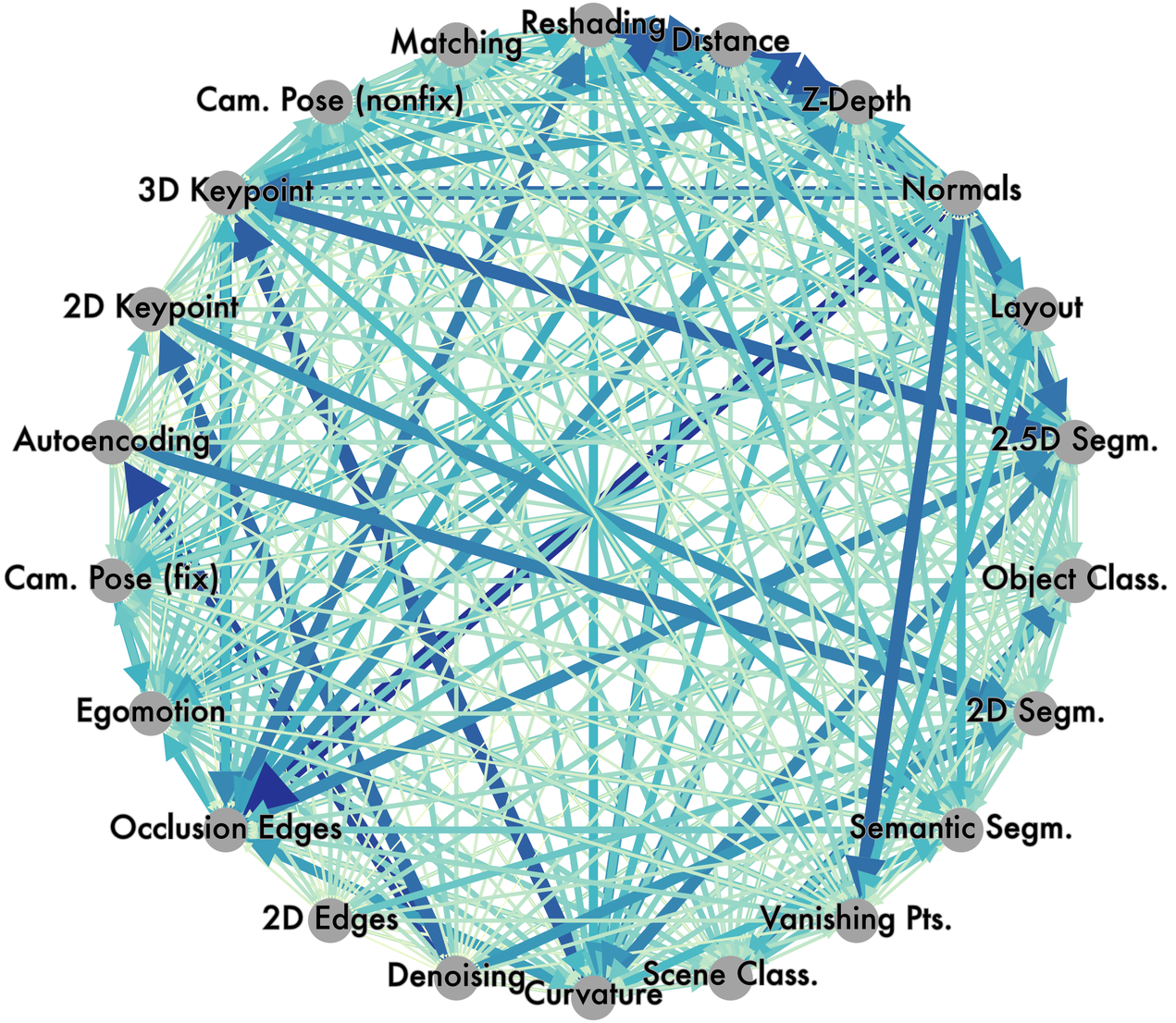
Redundancy

↓

Efficiency

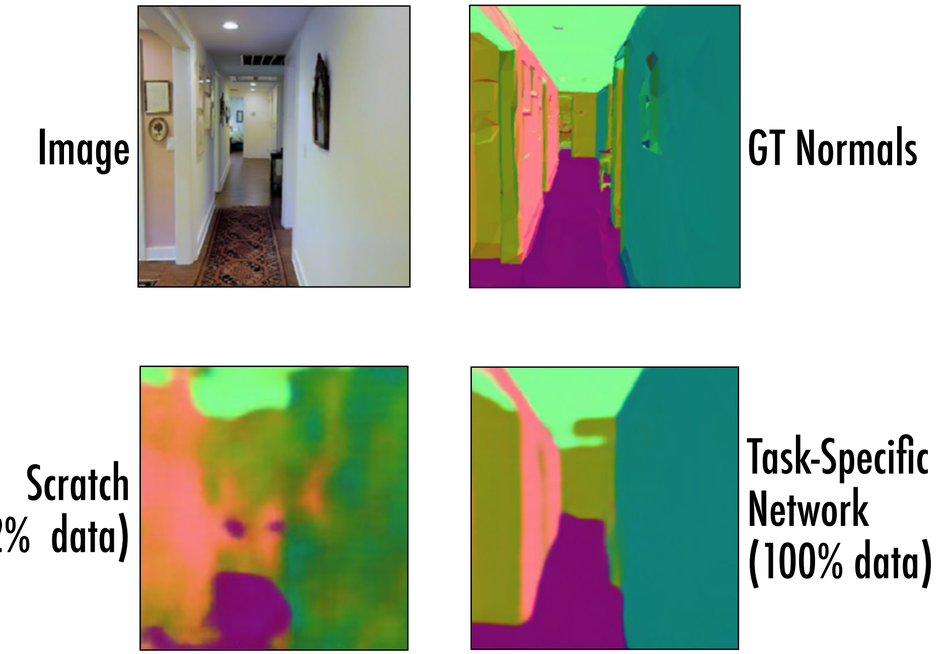
Supervision Efficiency

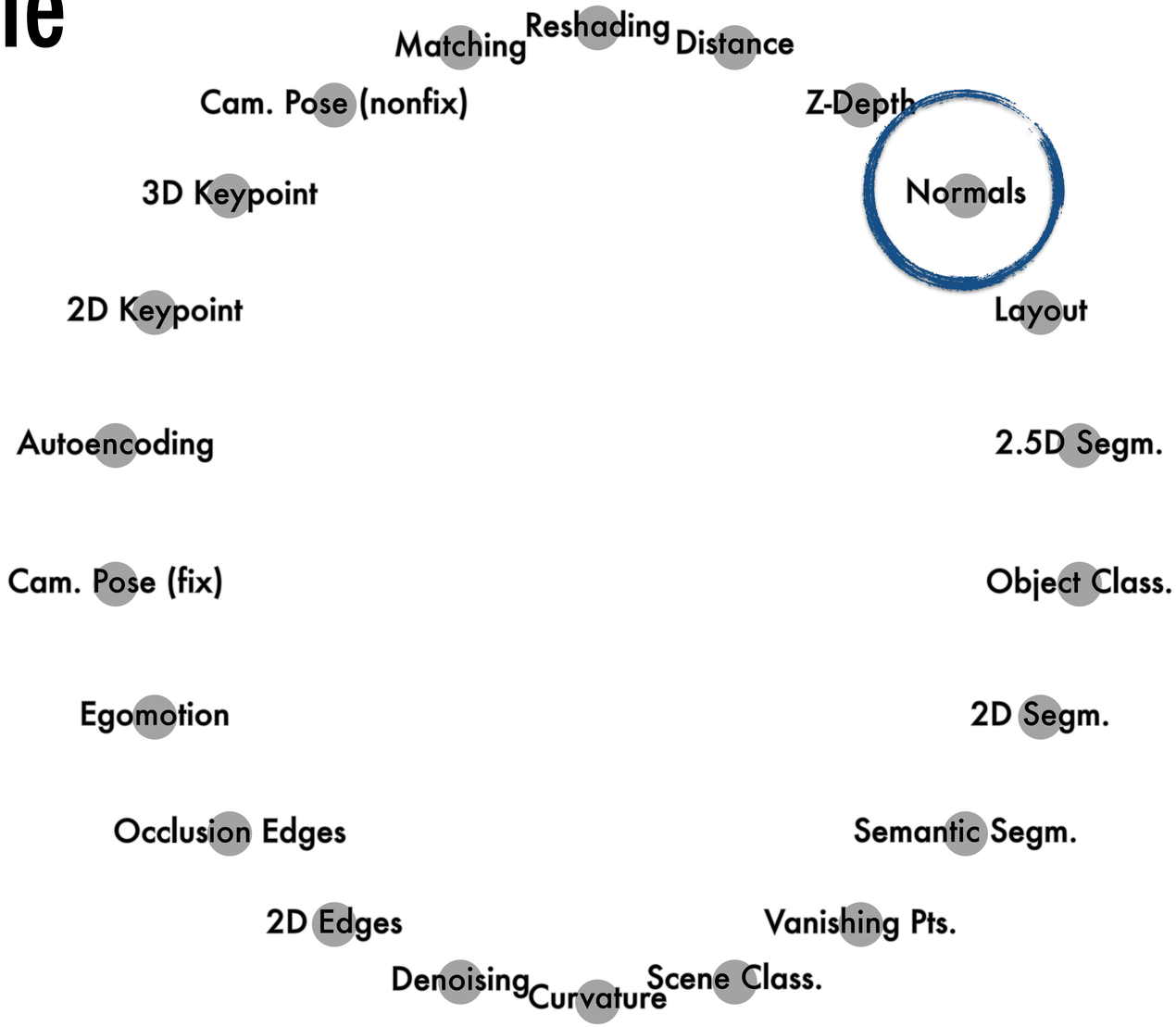
Transfer Learning:
Model developed for task X may be useful for solving task Y, if X and Y related. [1]



[1] West'07.

Transfer Learning Example





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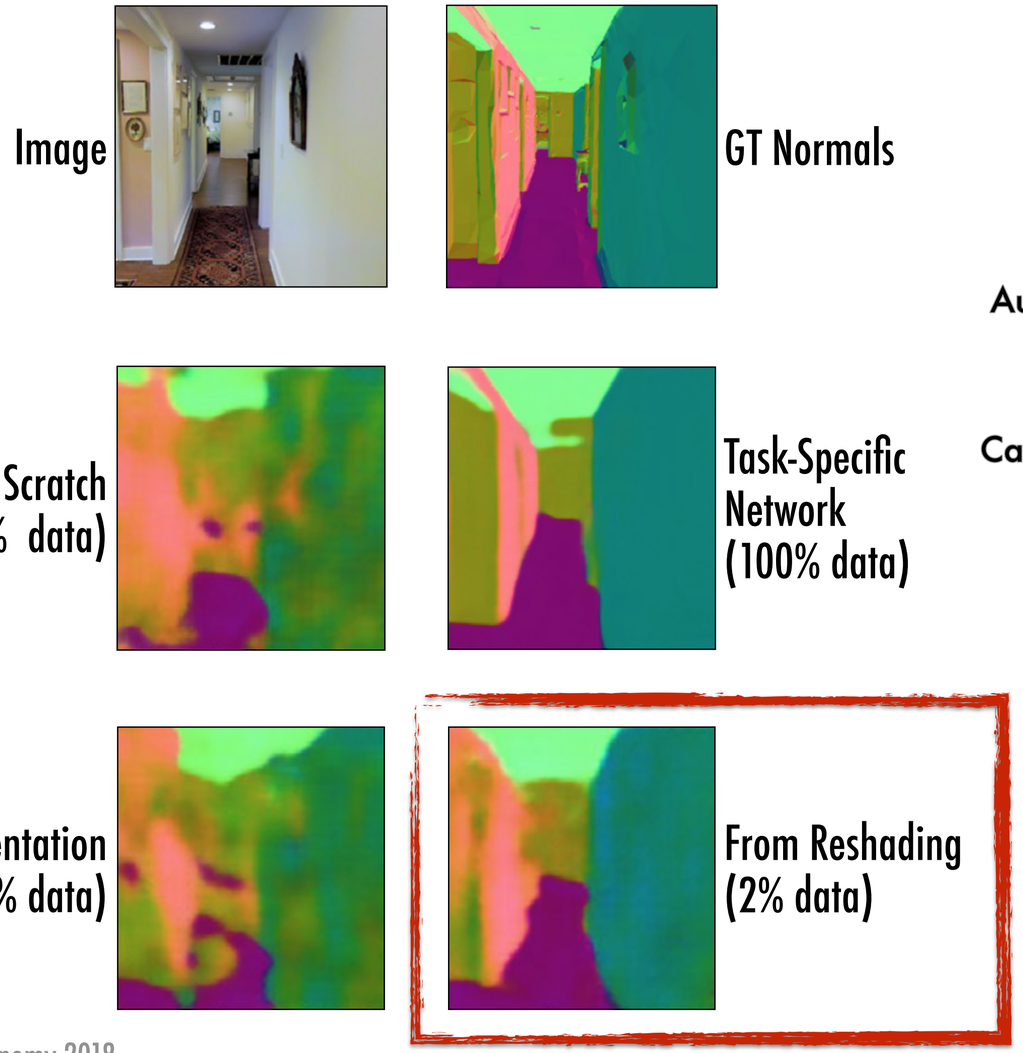
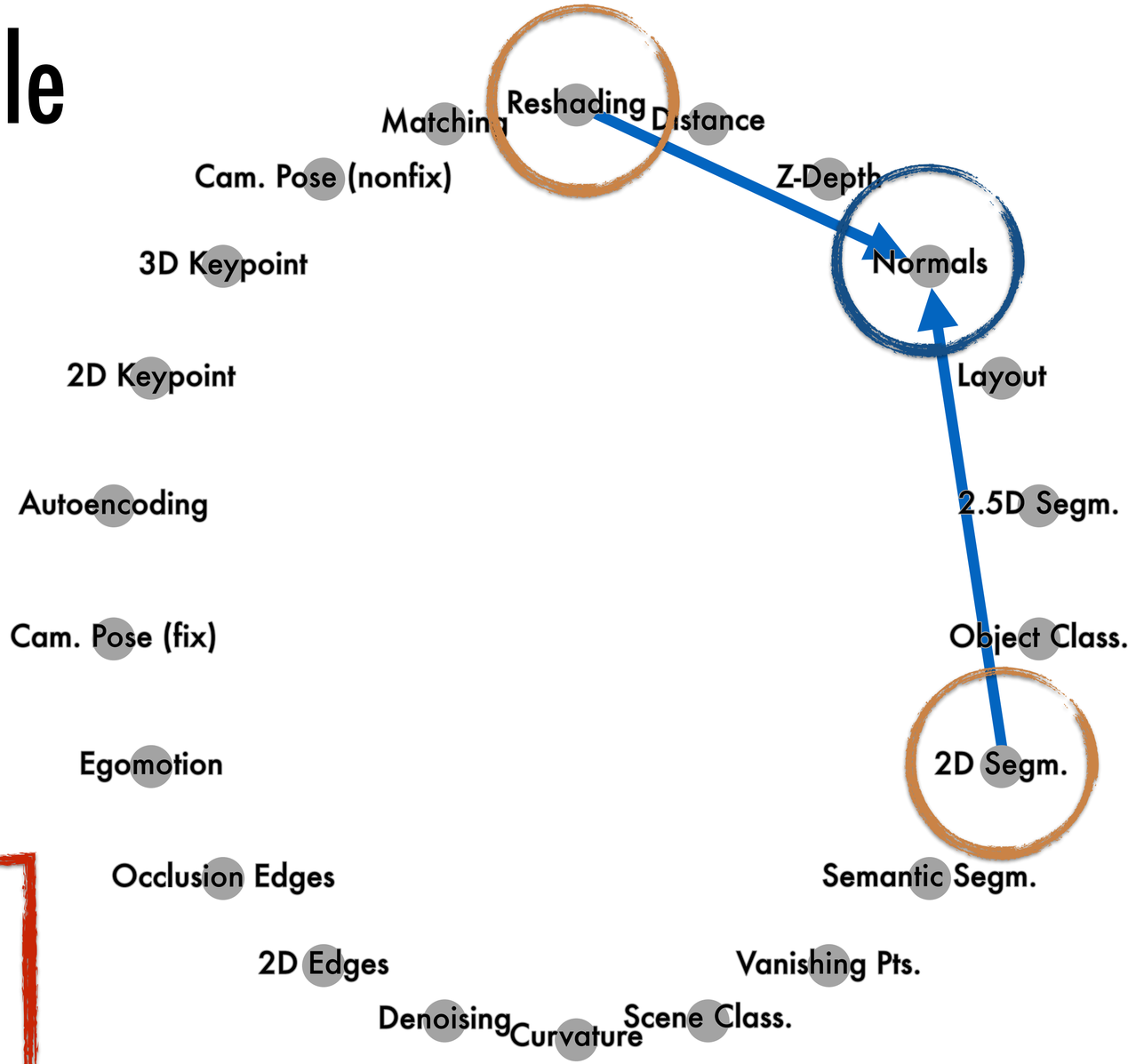
Transfer Learning Example





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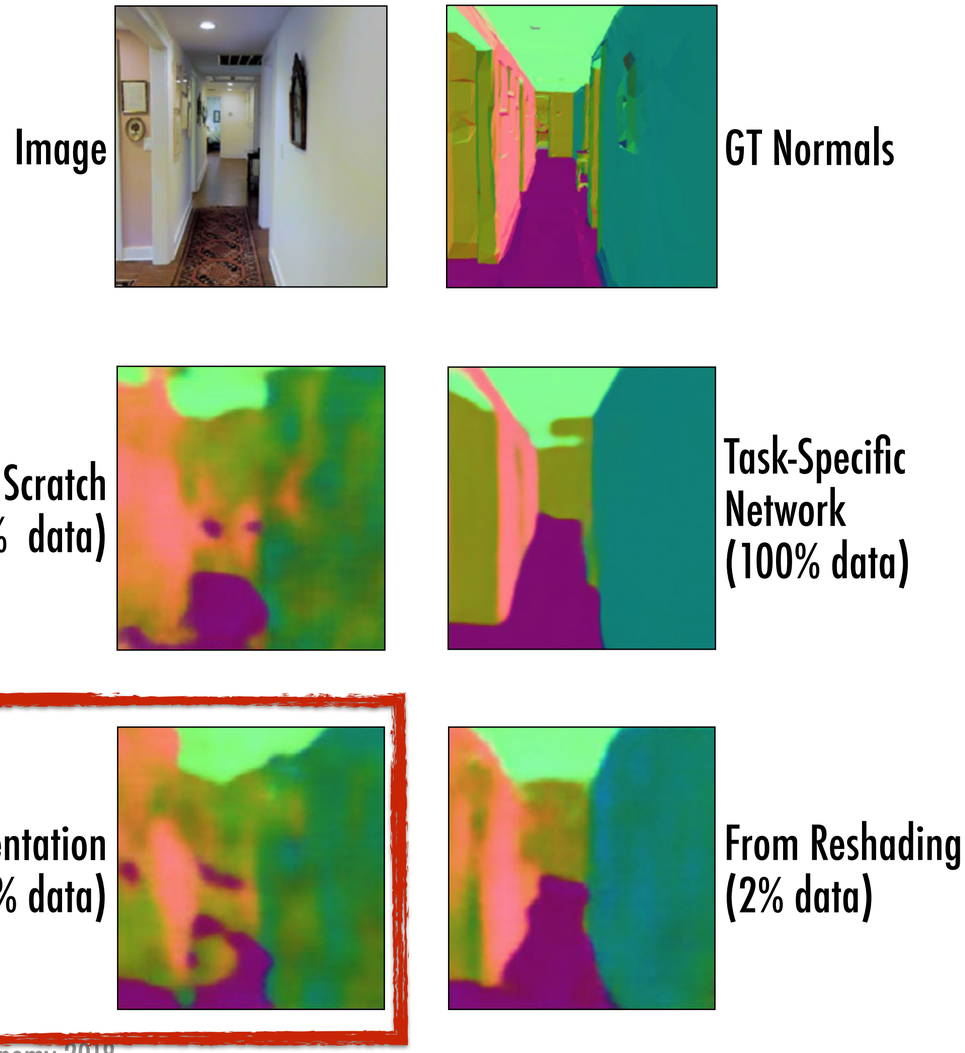
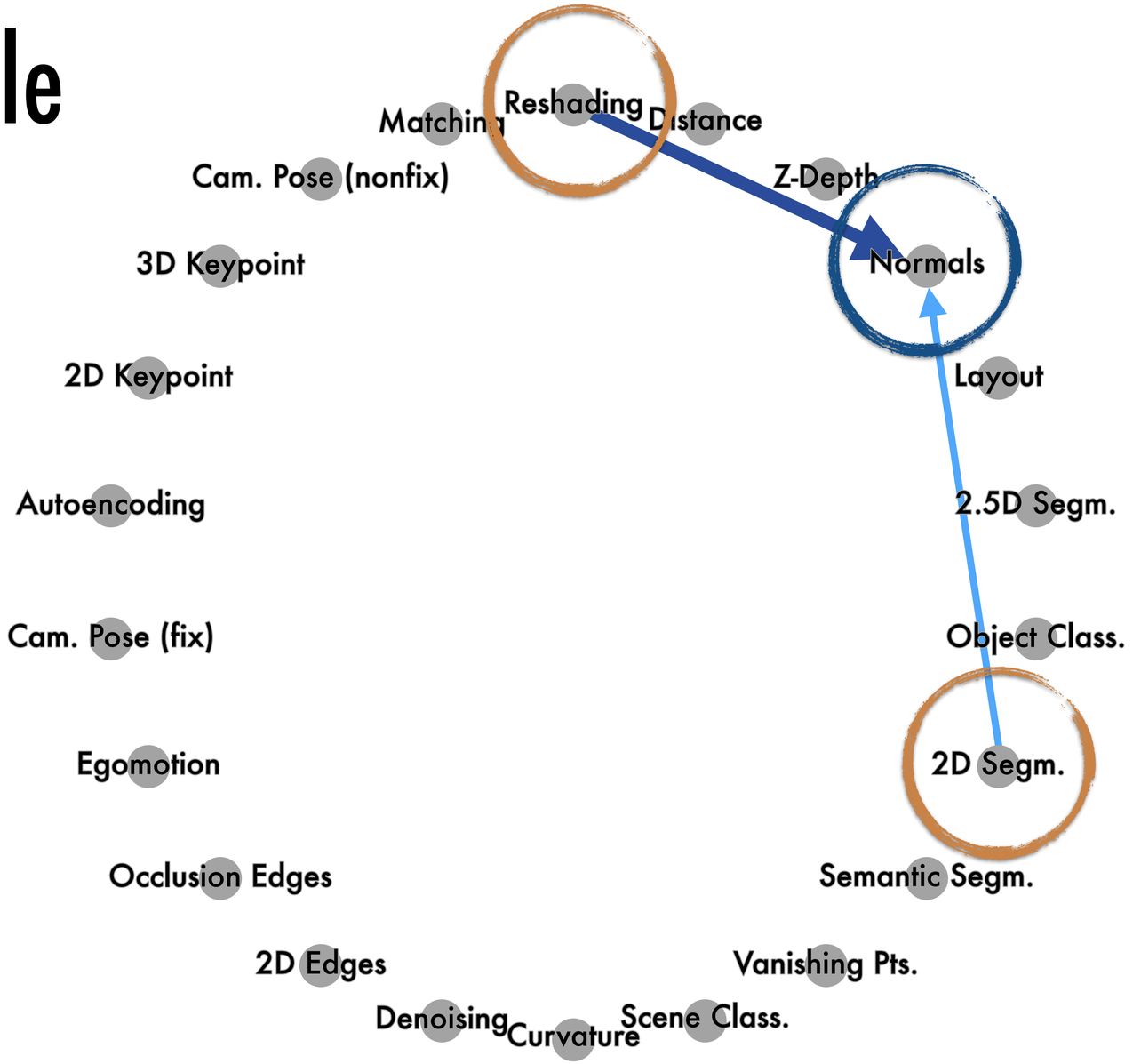
Transfer Learning Example





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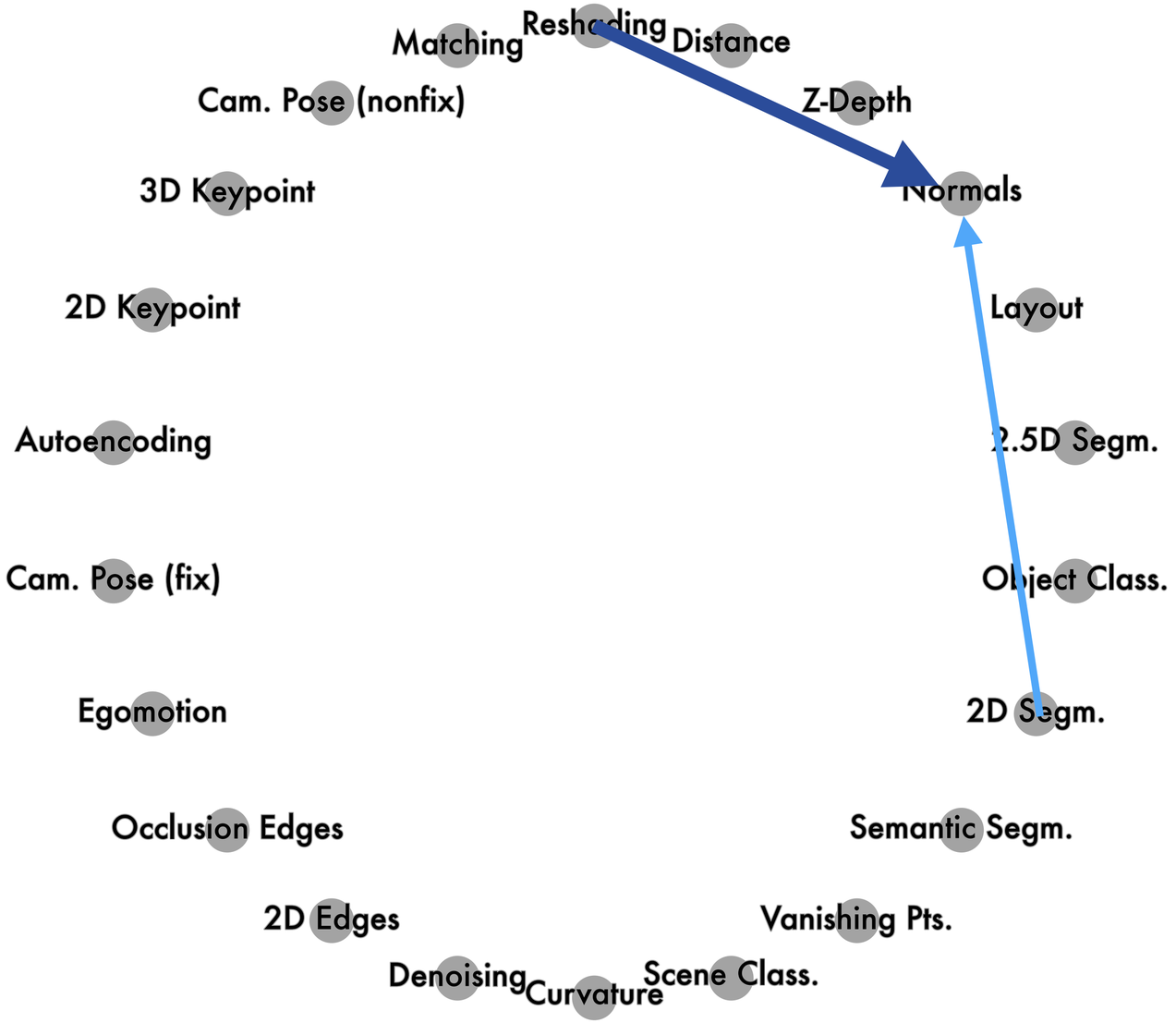

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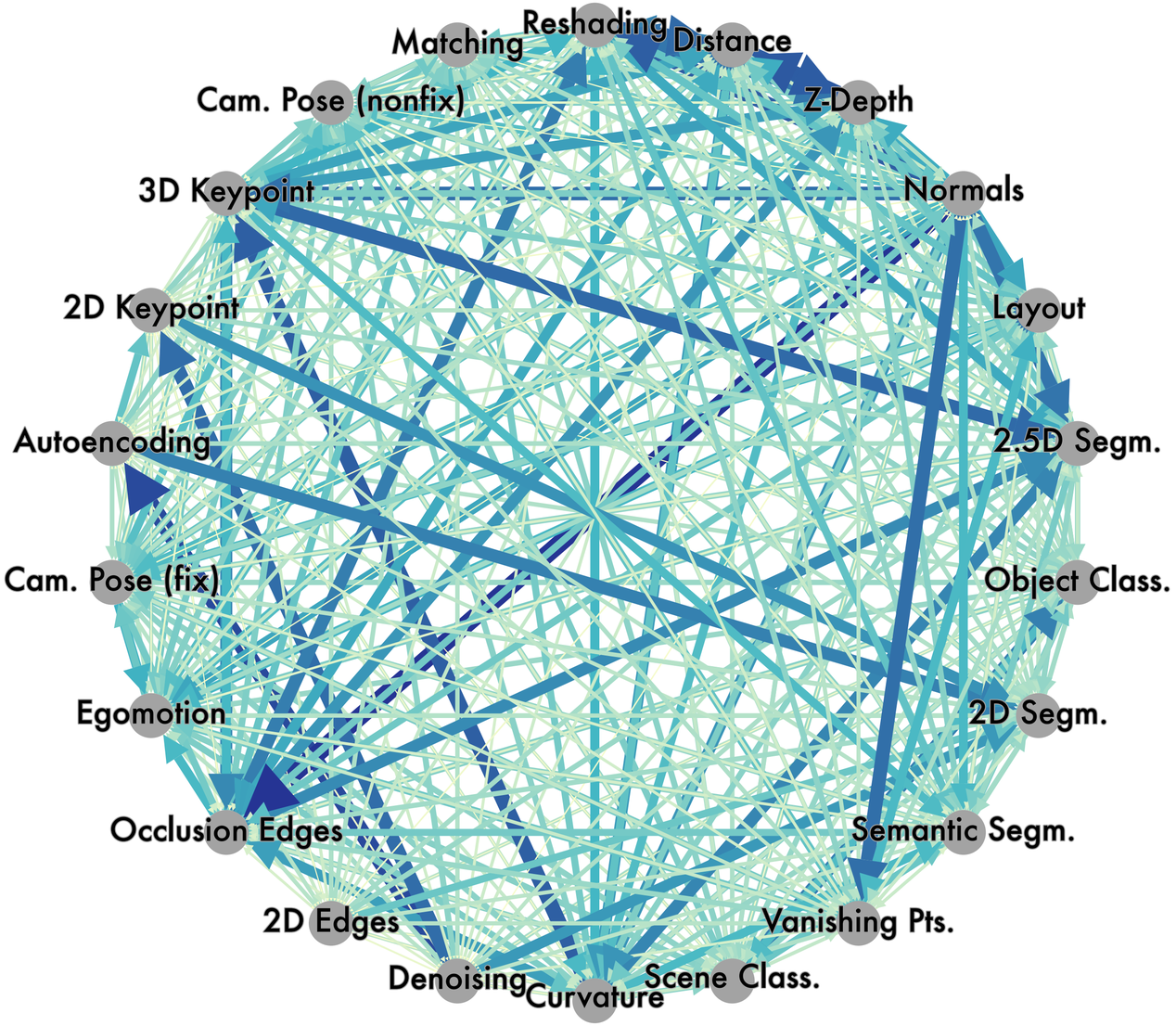
Dense Task Relationships

- Global window to redundancies



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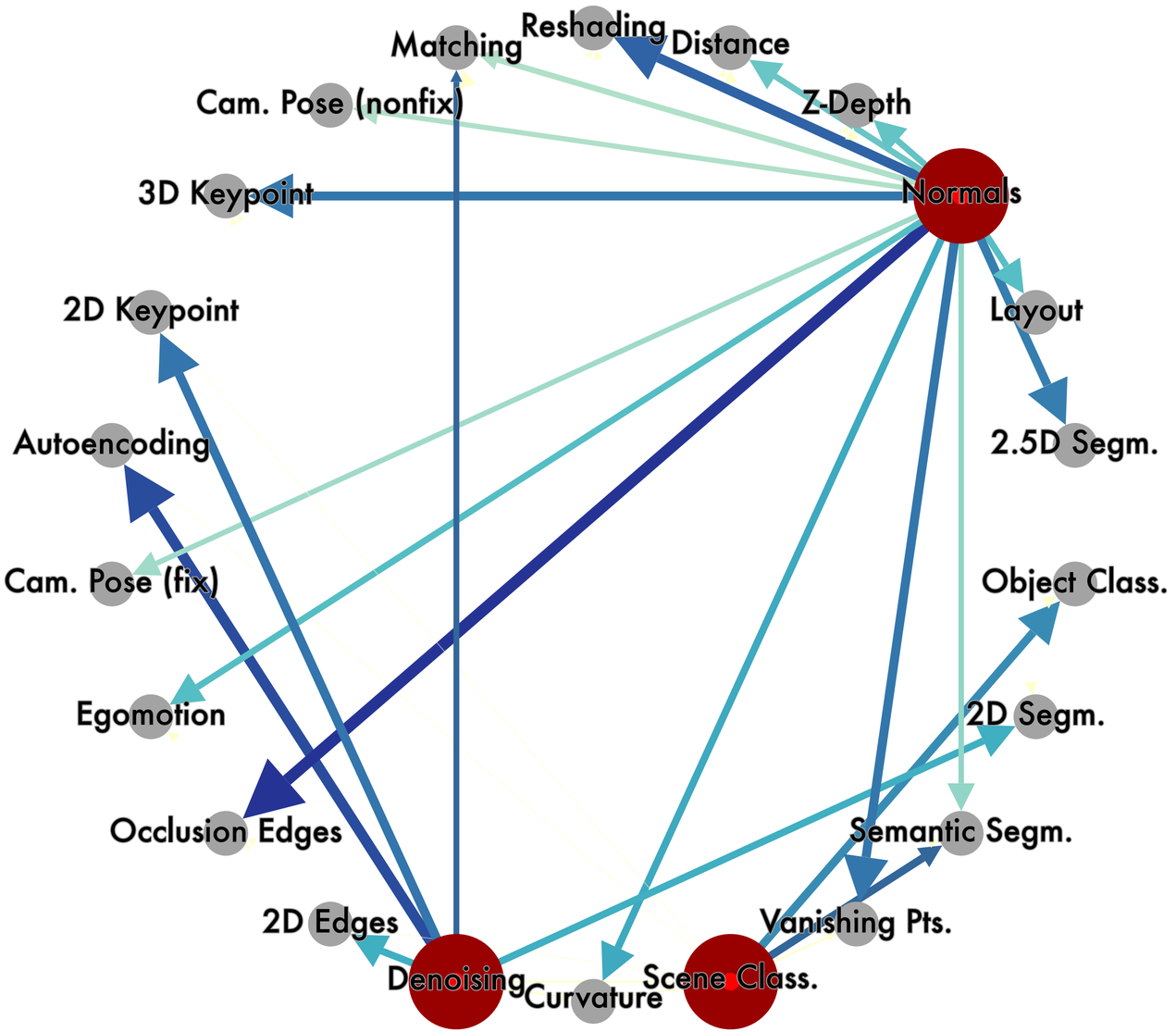
Dense Task Relationships

- Global window to redundancies
- Devise a policy to solve a set of tasks
  - in concert
  - recycle supervision



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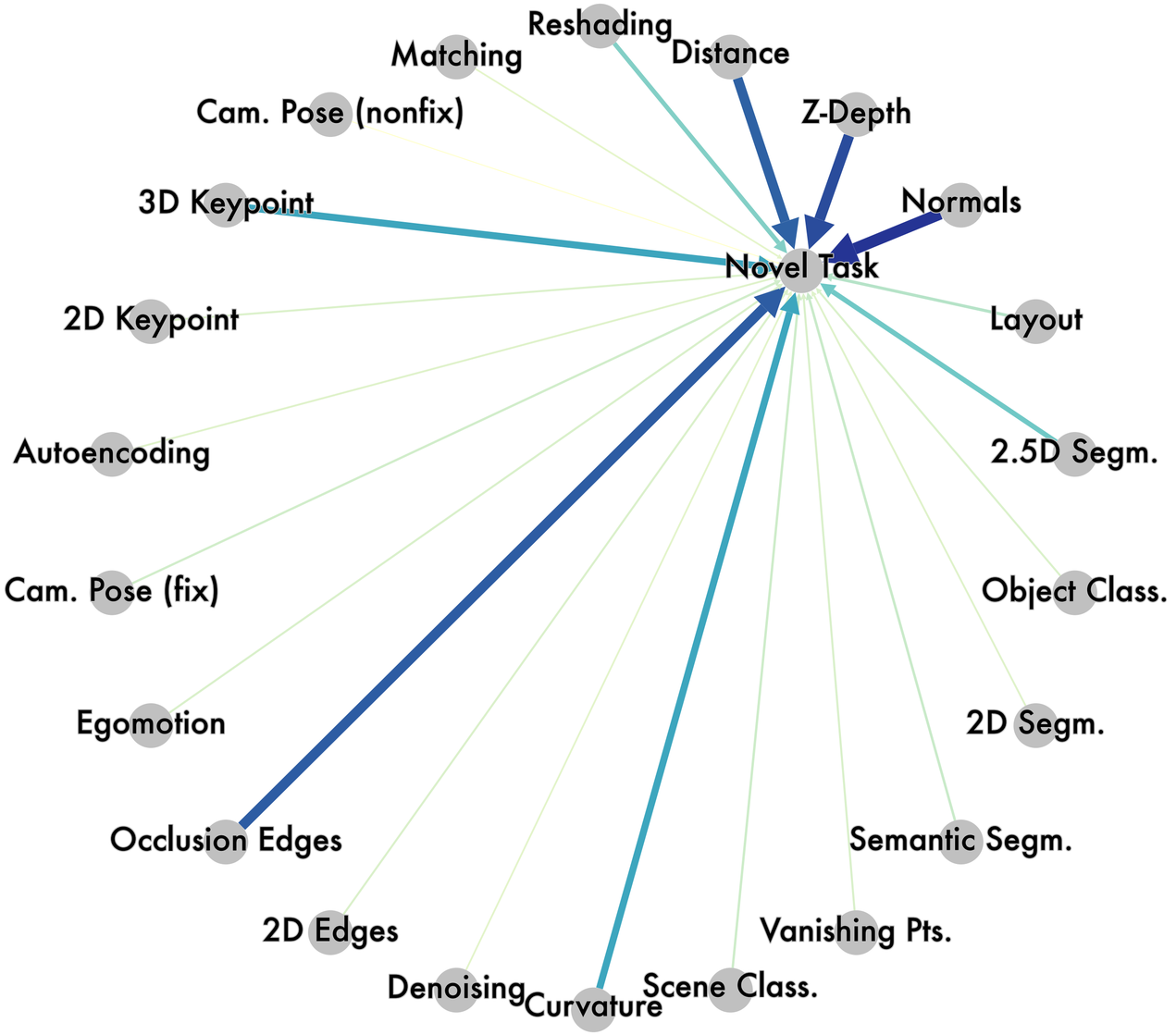
Dense Task Relationships

- Global window to redundancies
- Devise a policy to solve a set of tasks
  - in concert
  - recycle supervision
- Solve a novel task with little data
  - by "insertion" into this structure



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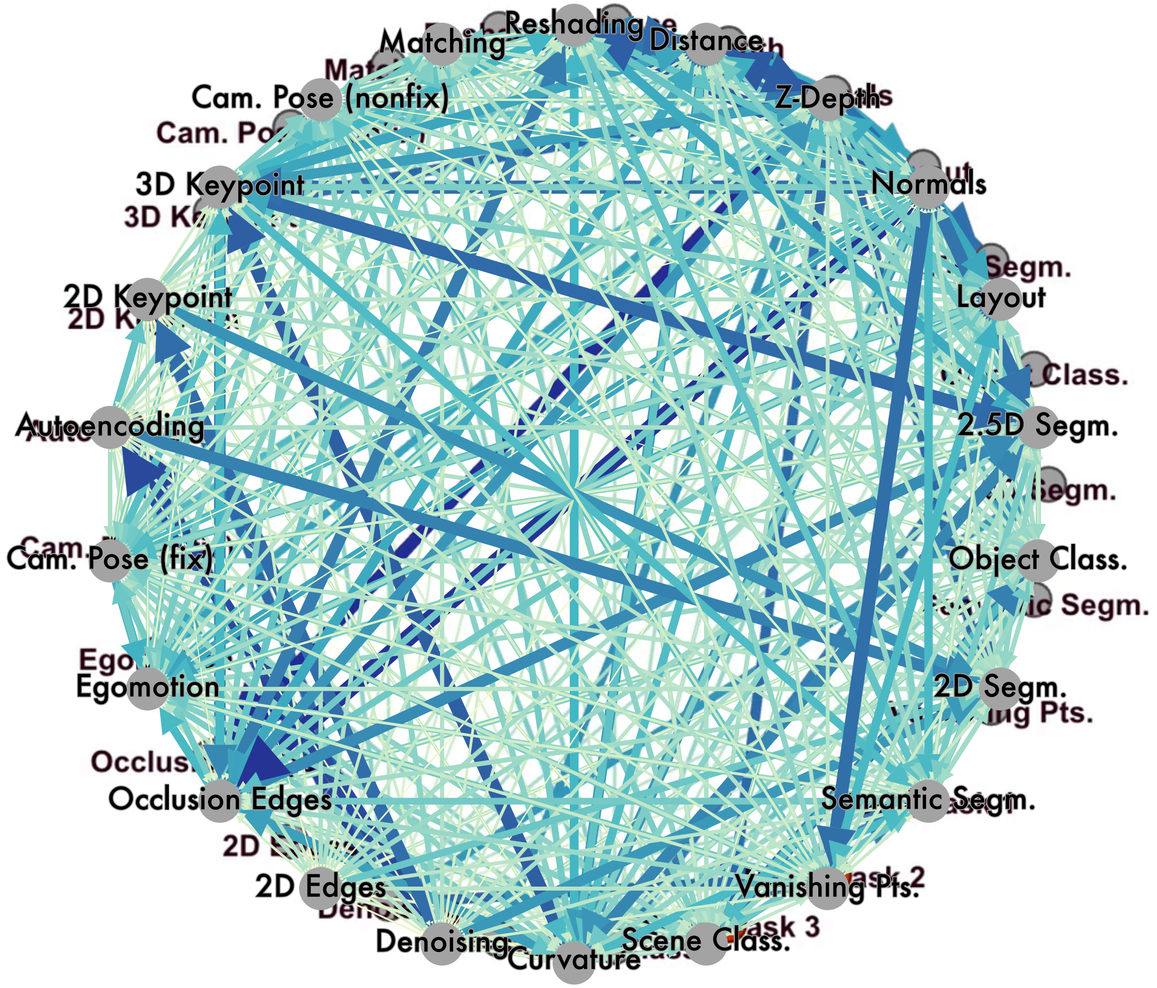
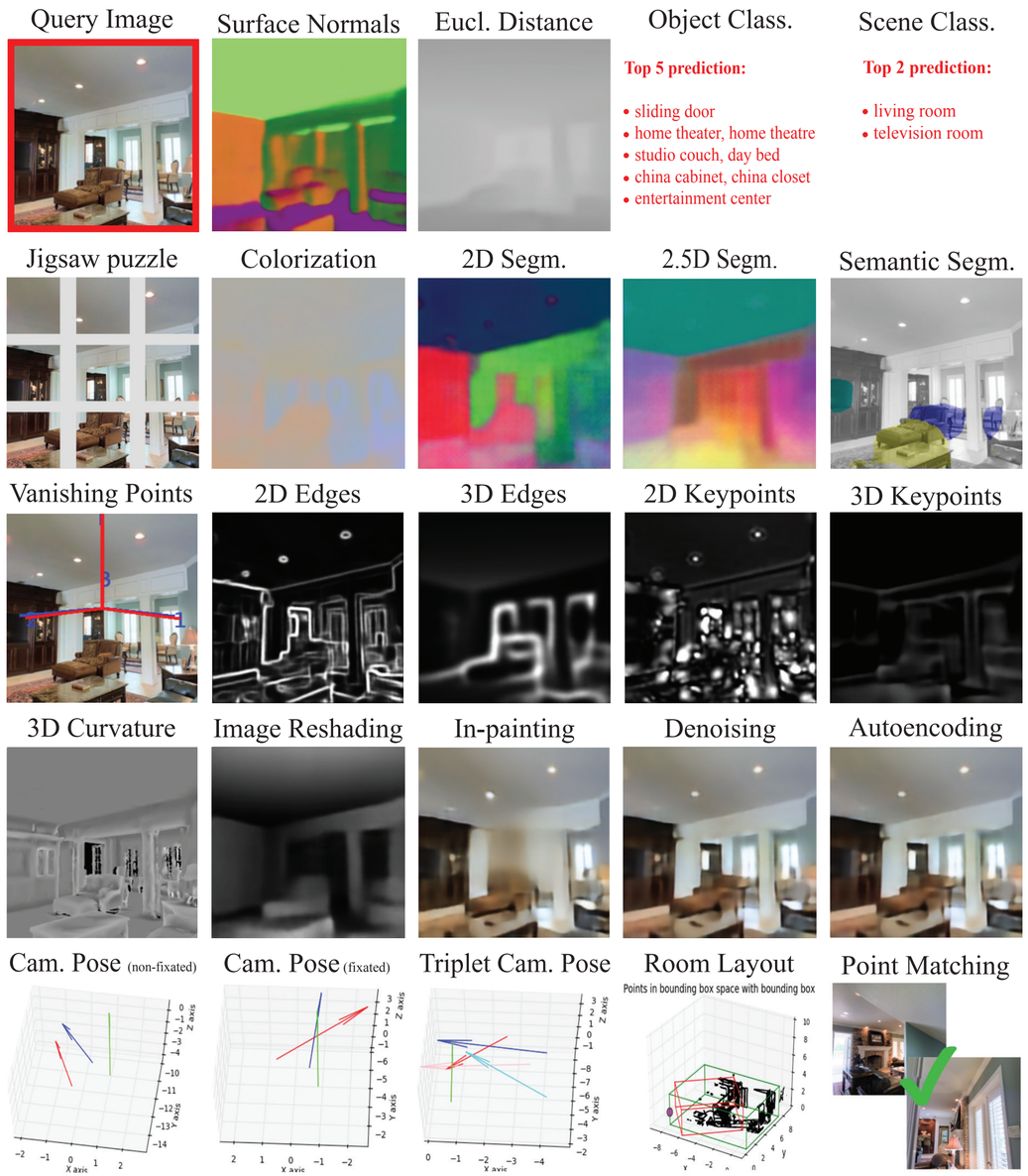
Taskonomy!

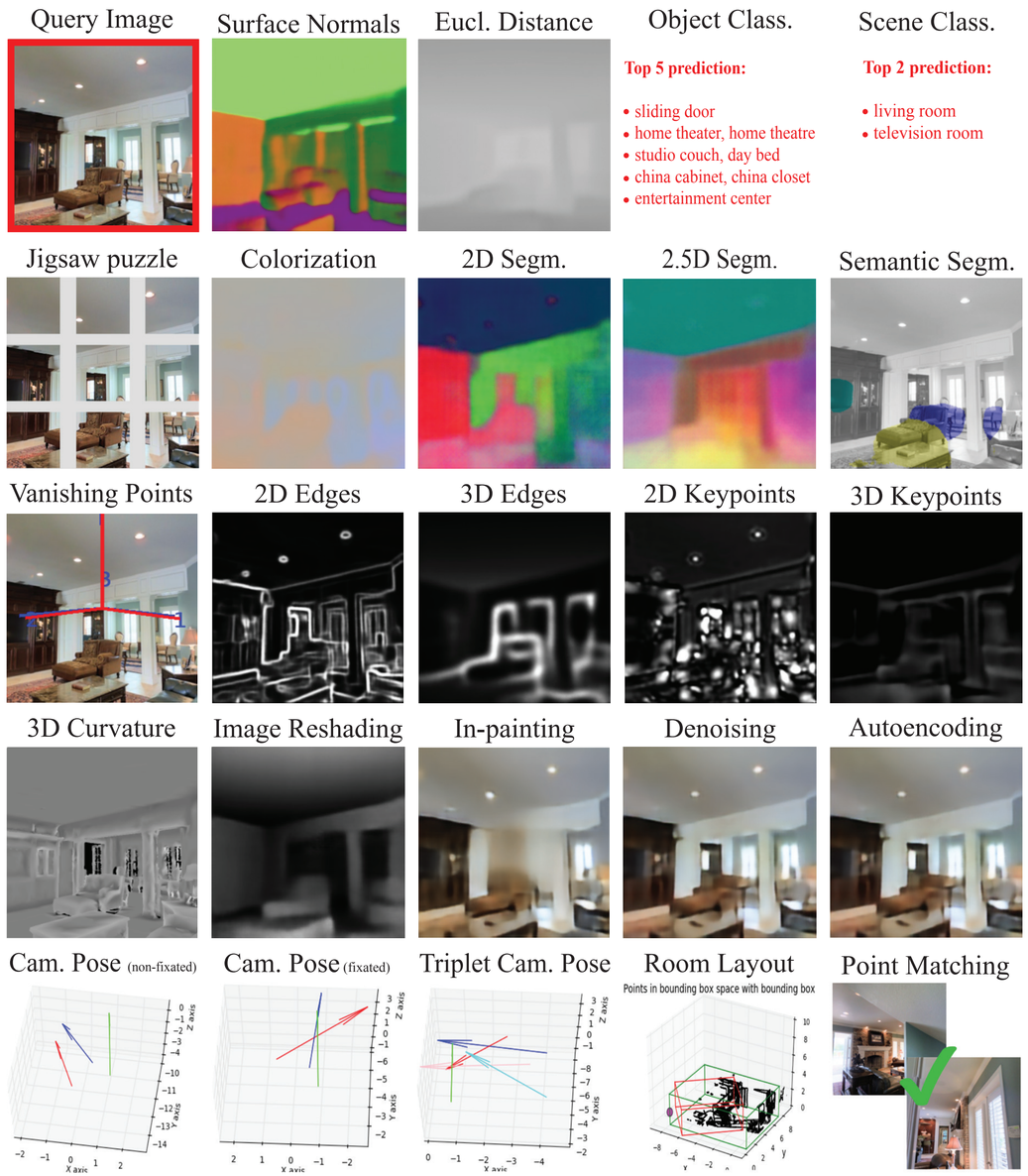
- A fully computational method for quantifying task relationships
- Extracting a structure out of them
- Unified model for transfer learning
- **task** tax**onomoy** ≈ taskonomy



- **Task Bank**
  - 26 Semantic, 2D, 3D, and tasks



- **Task Bank**
  - 26 Semantic, 2D, 3D, and tasks
- **Dataset**
  - 4 million <u>real</u> images
  - <u>Each image</u> has the GT label for <u>all tasks</u>



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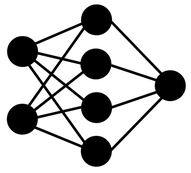
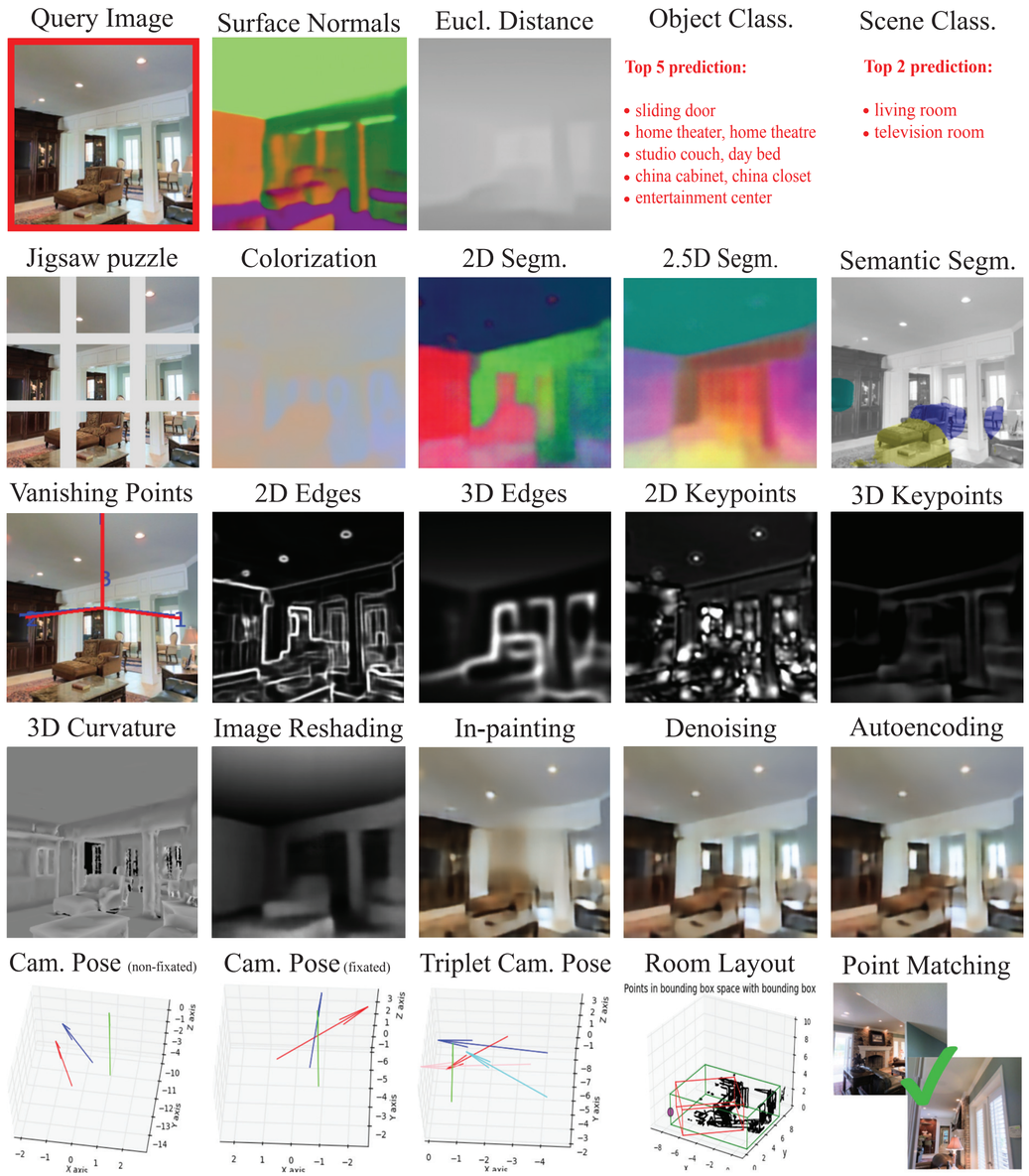
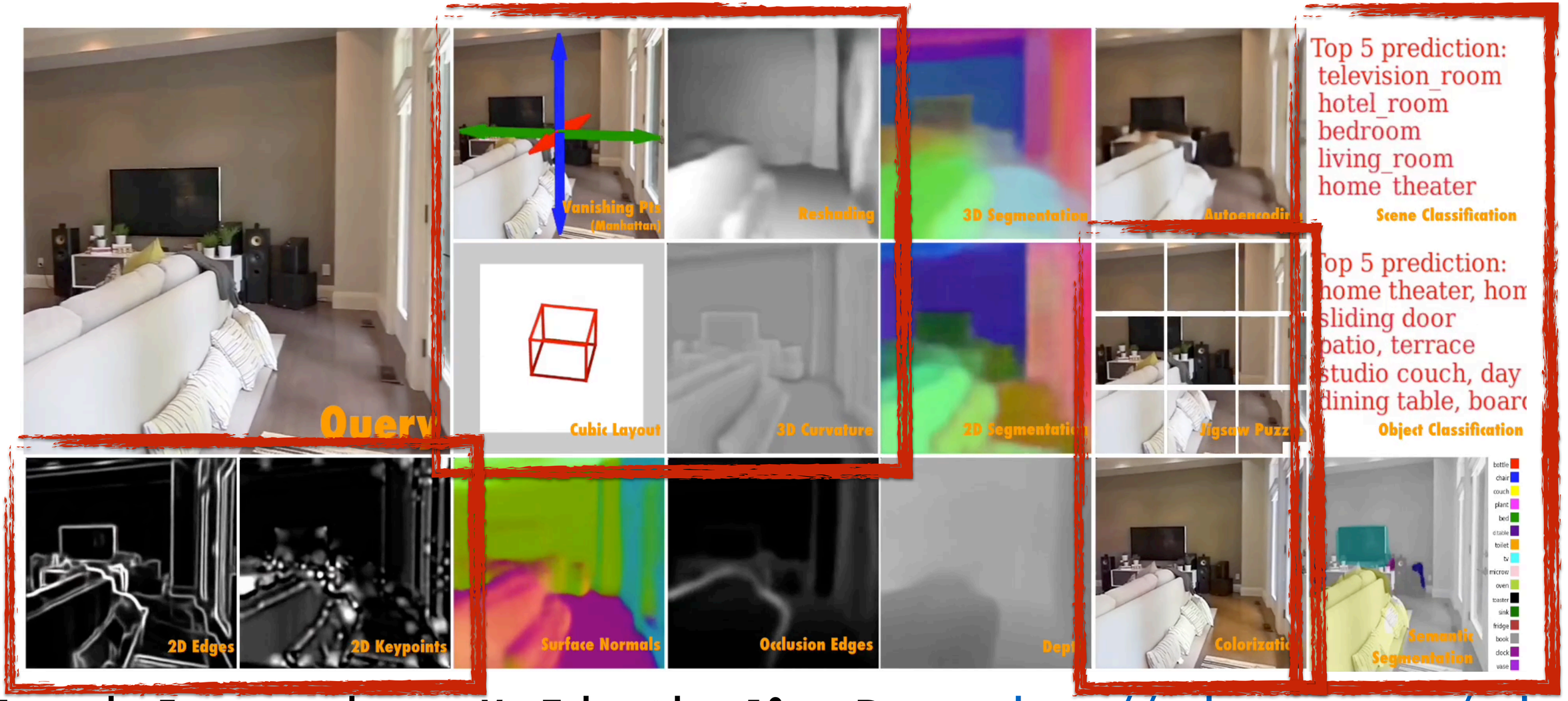
- **Task Bank**
  - 26 Semantic, 2D, 3D, and tasks
- **Dataset**
  - 4 million real images
  - Each image has the GT label for all tasks
- **Task-Specific Networks**
  - 26 x 

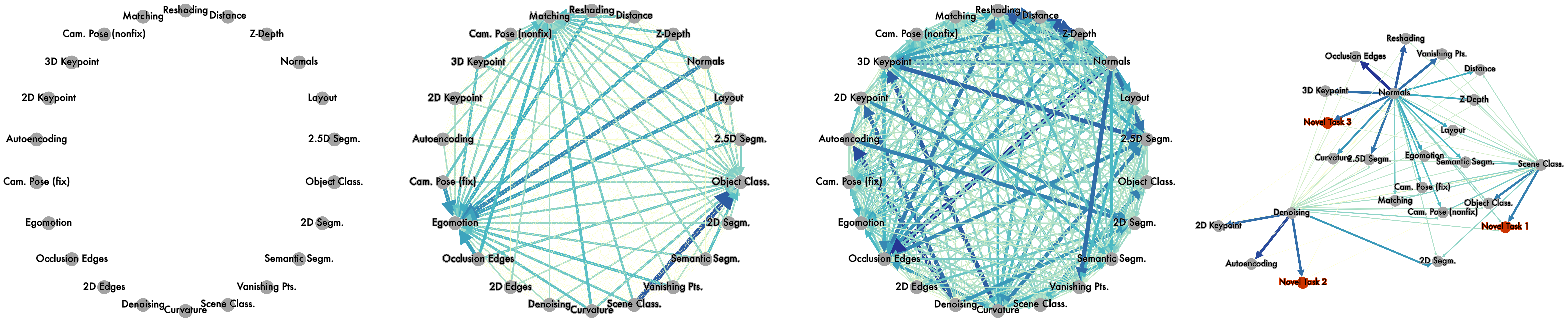


Task-Specific Networks



Frame-by-Frame results on a YouTube video. **Live Demo**: https://taskonomy.vision/tasks

Modeling



I: Task-Specific Modeling → II: Transfer Modeling → III: Normalization (AHP) → IV: Taxonomy Extraction (BIP)

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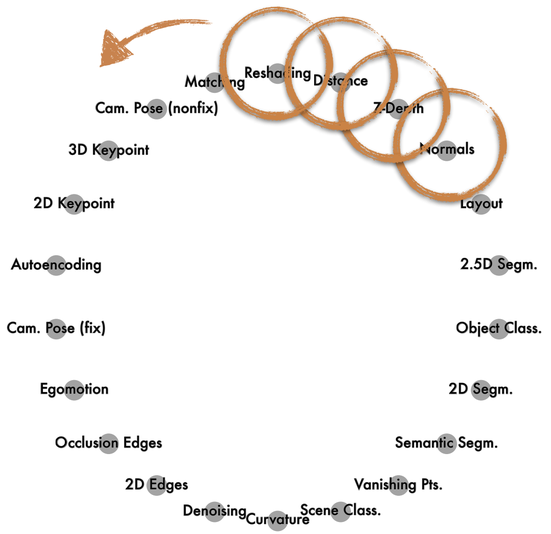
I: Task-Specific Modeling



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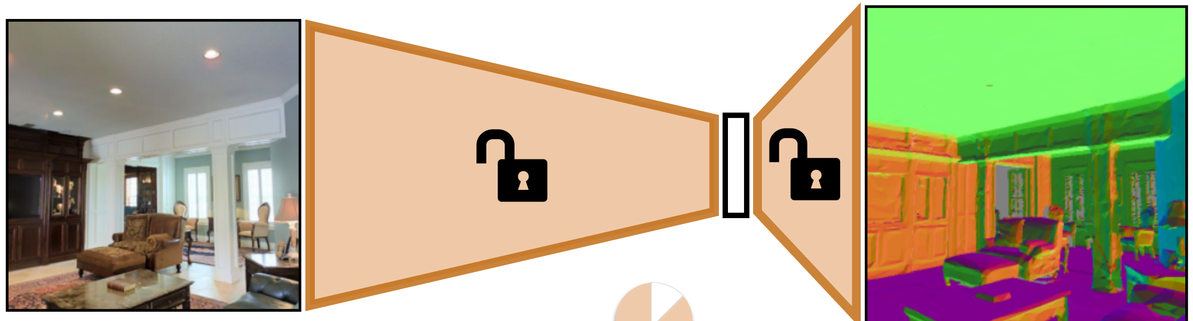
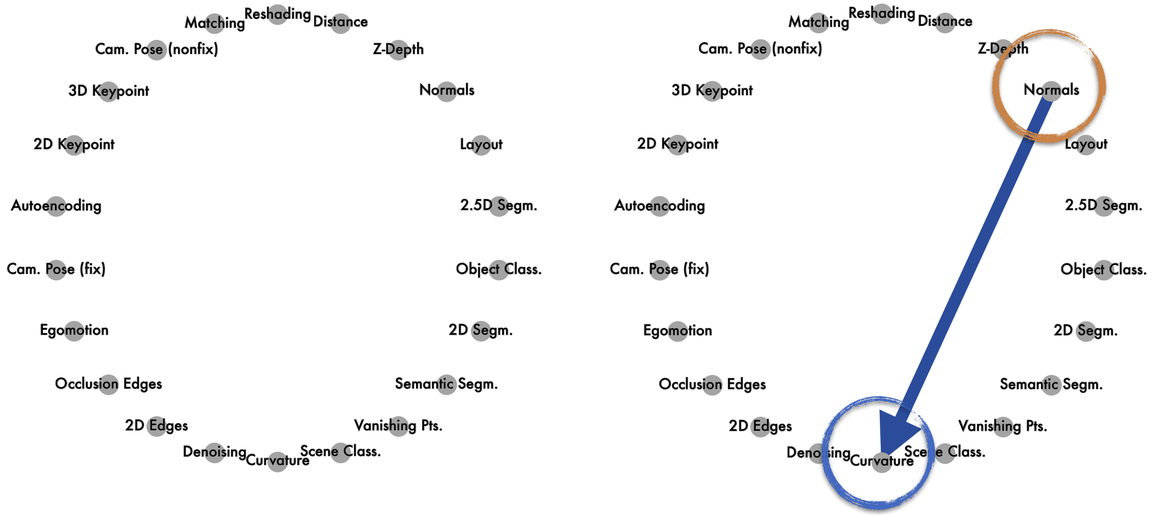


Image

Training data

Source Output (normals)

II: Transfer Modeling



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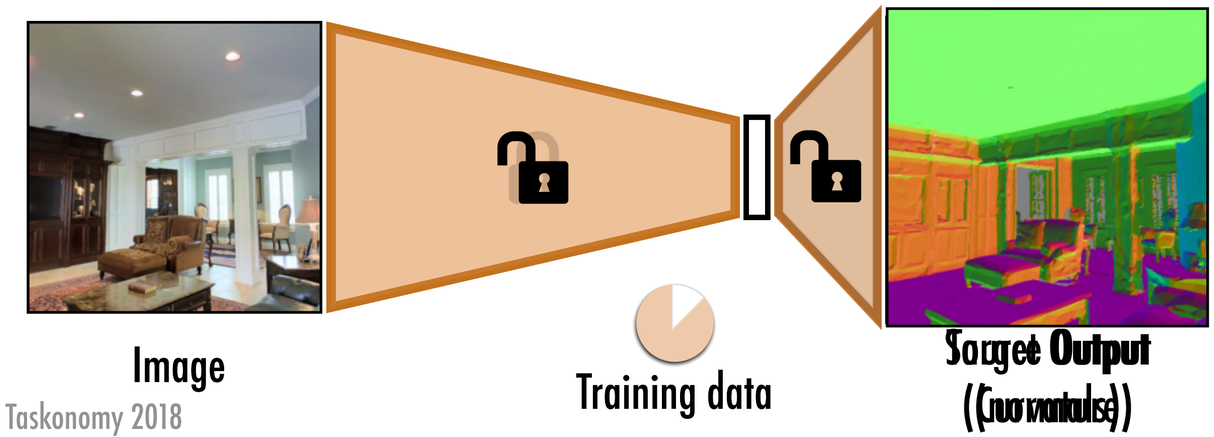

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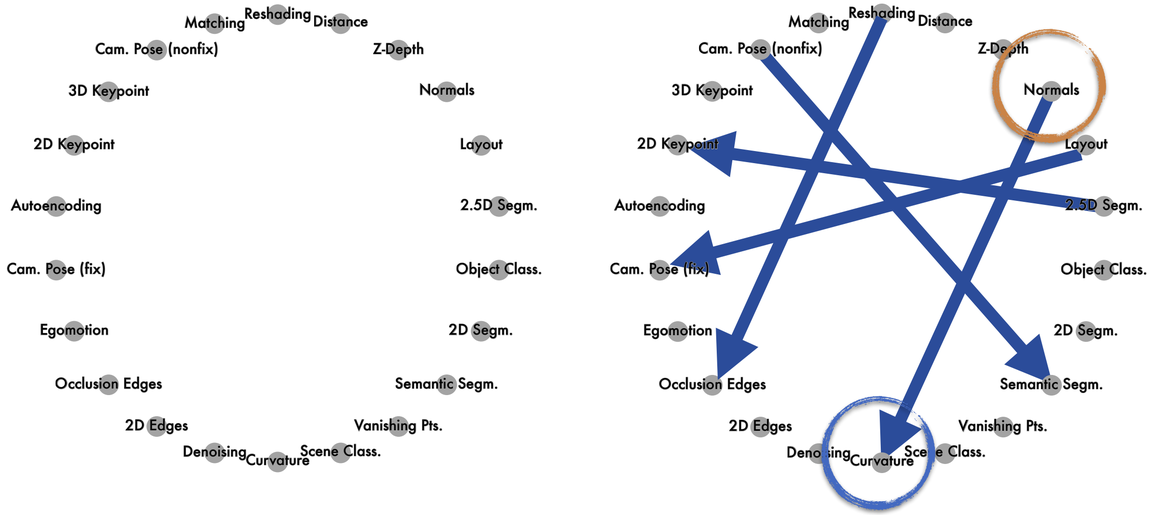
II: Transfer Modeling



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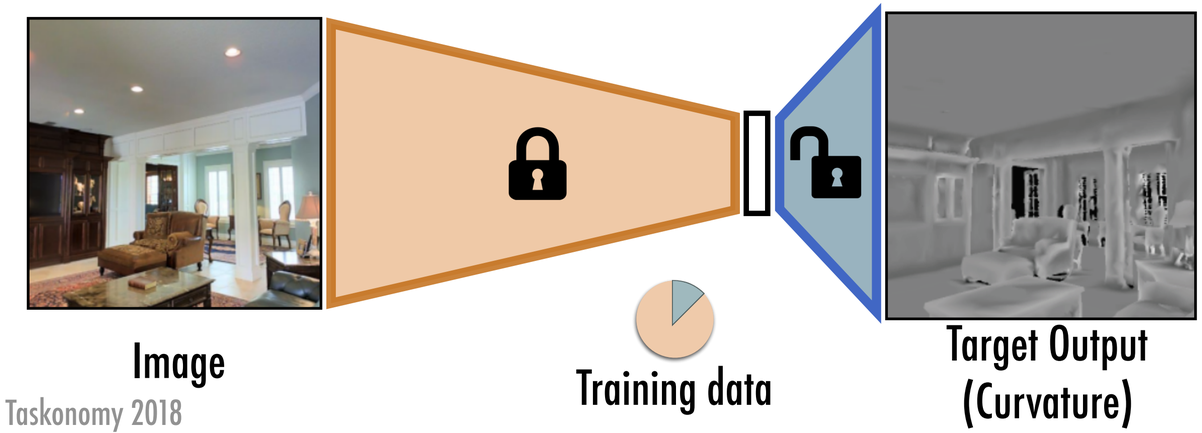

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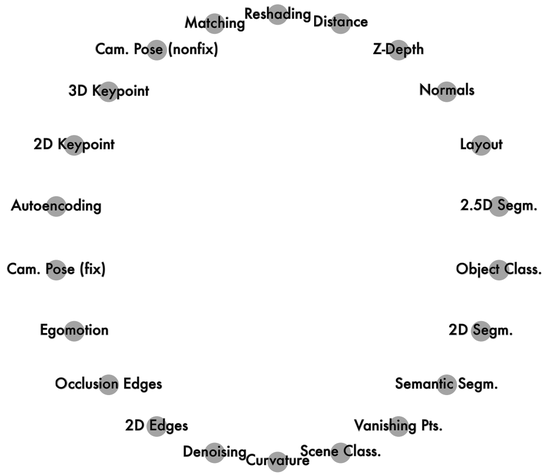

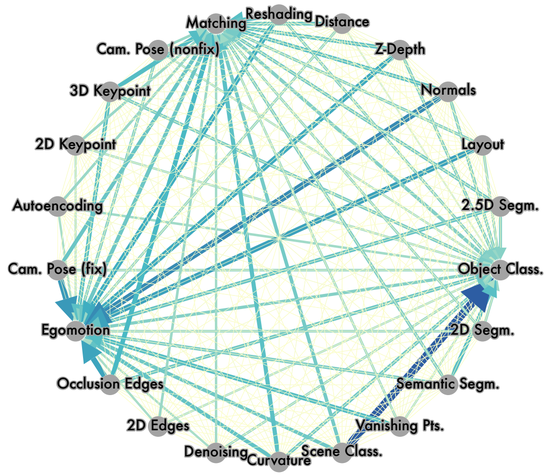

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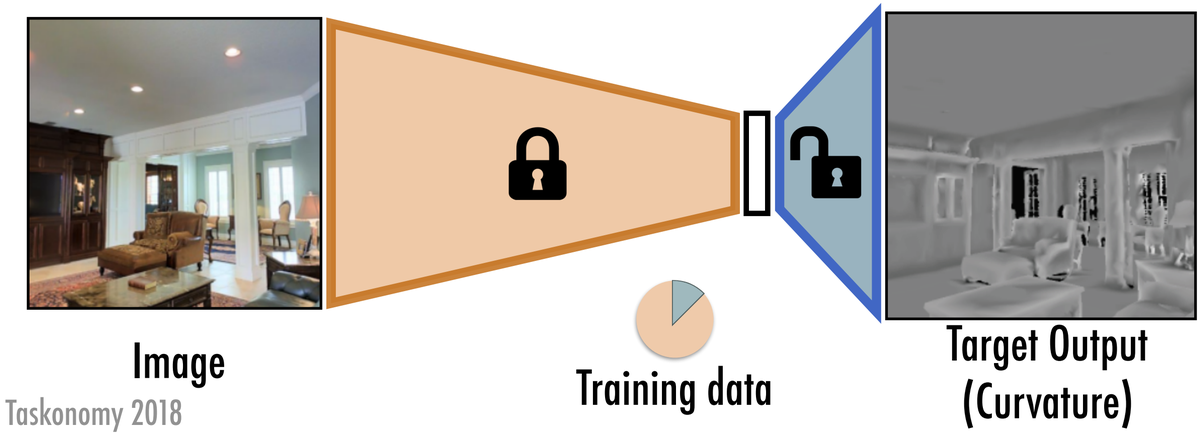

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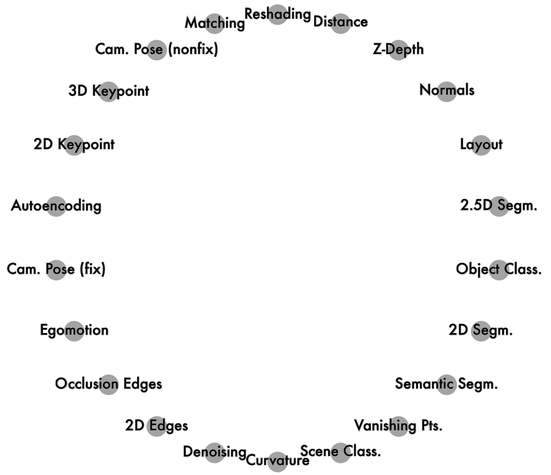
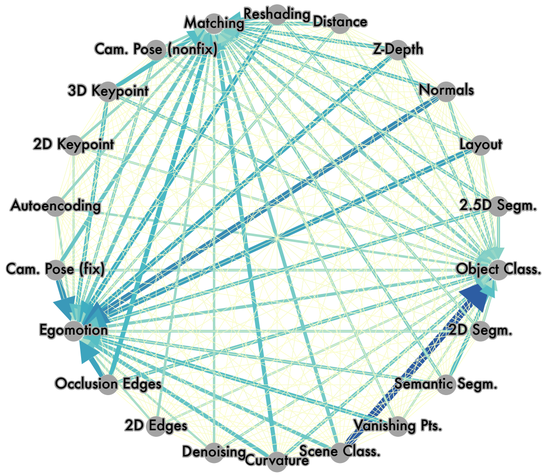
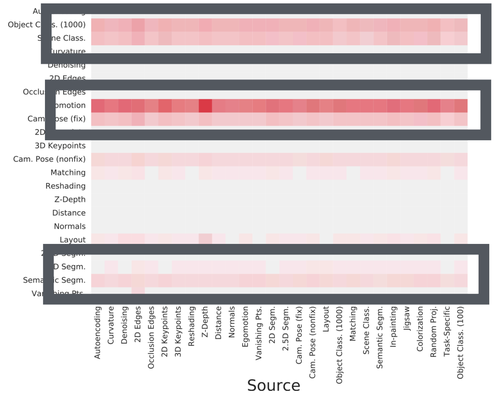
III: Normalization



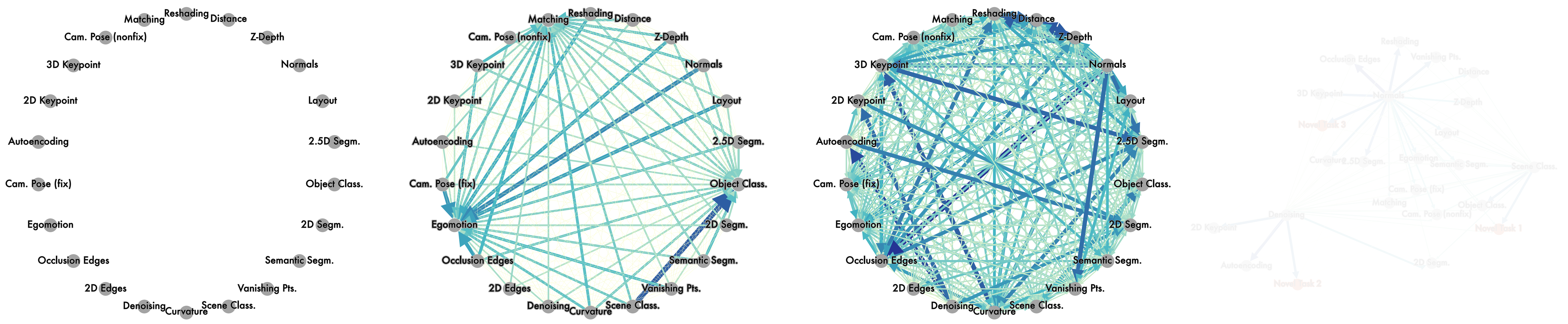


I: Task-Specific Modeling → II: Transfer Modeling → III: Normalization (AHP) → IV: Taxonomy Extraction (BIP)

Adjacency Matrix (pre-normalization)



III: Normalization



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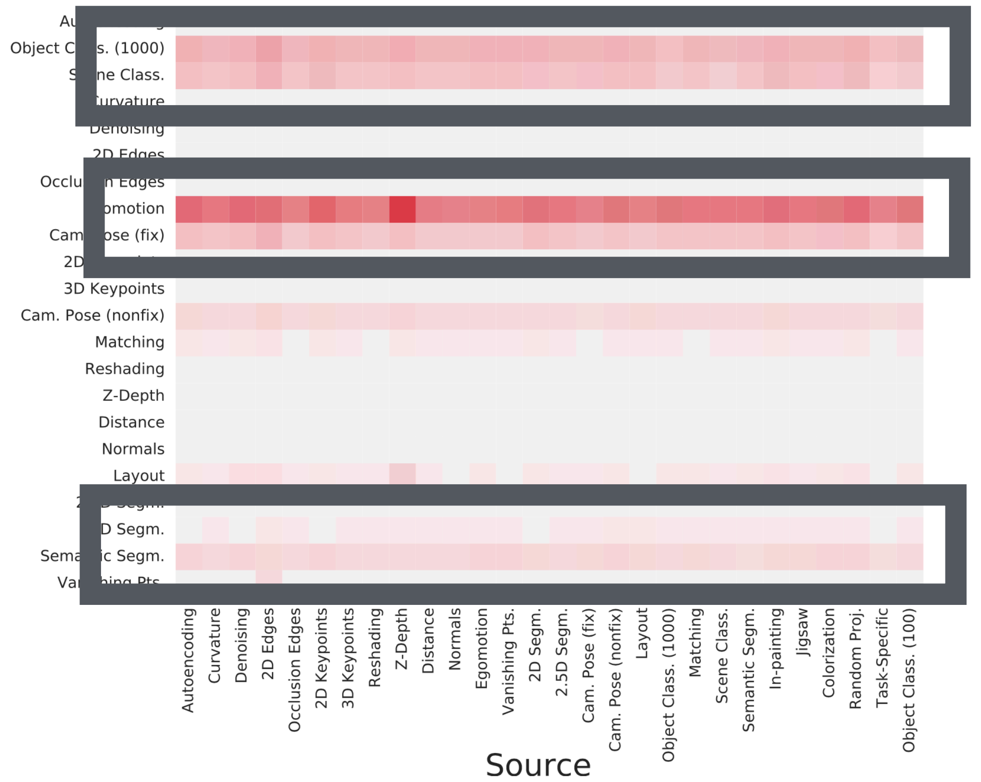
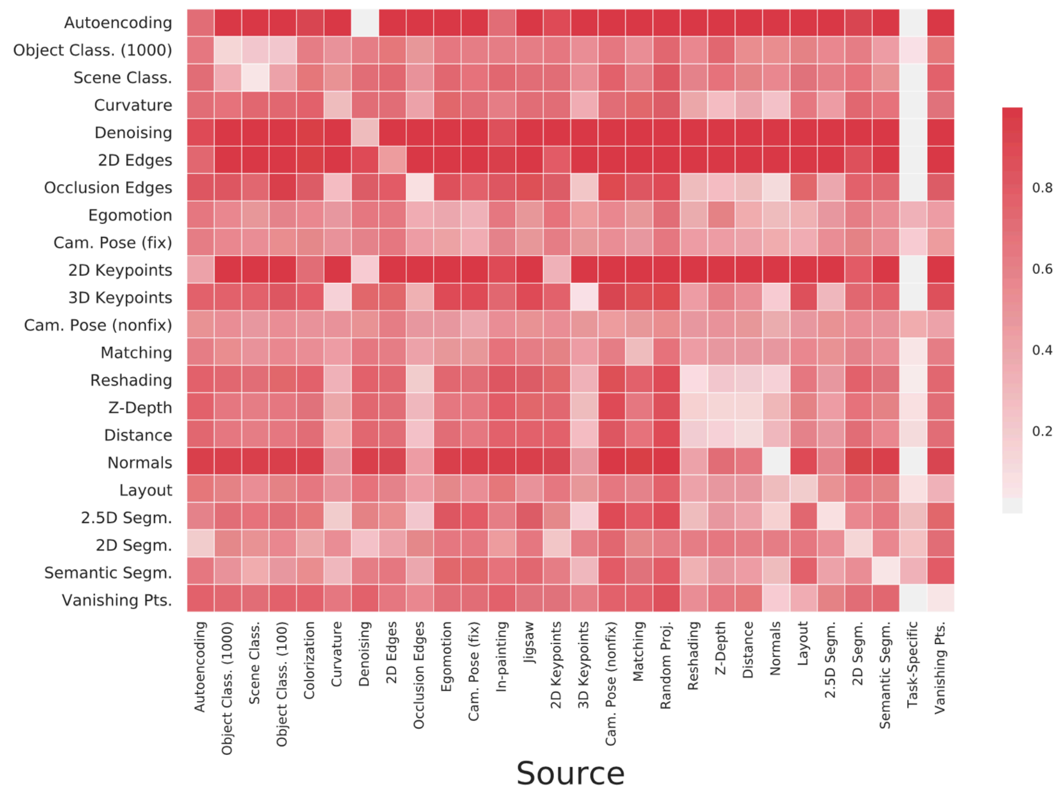
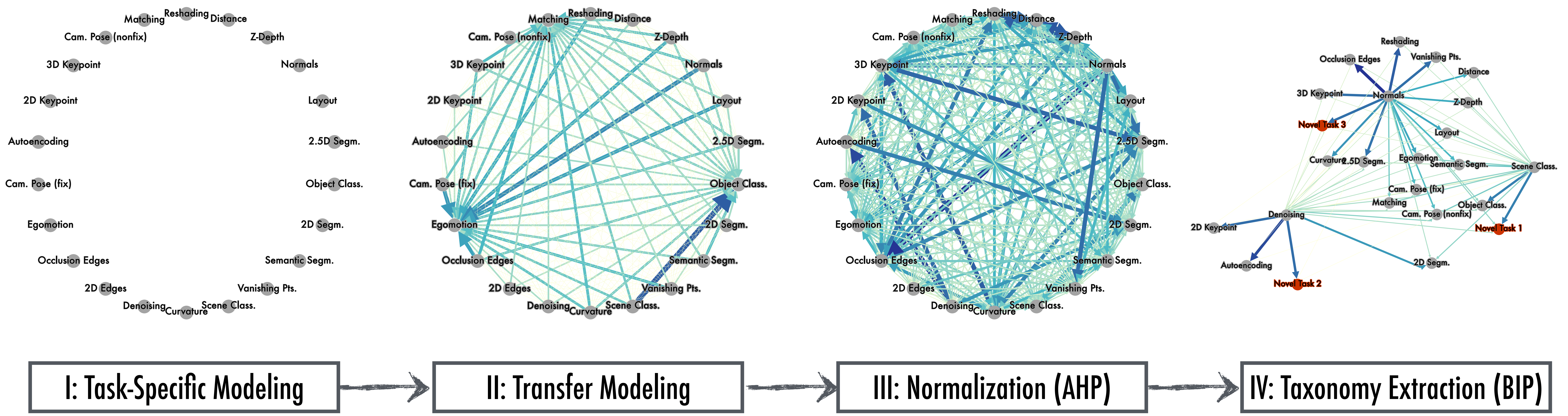


Adjacency Matrix (post-normalization)



Ordinal Normalization - Analytic Hierarchical Process. (AHP)

IV: Taxonomy Extraction



- **Taxonomical structure:**
  - Sparsified
  - What are best source tasks
  - What sources for each target
  - Out-of-dictionary tasks
  - Maximize performance while constrained by some budget

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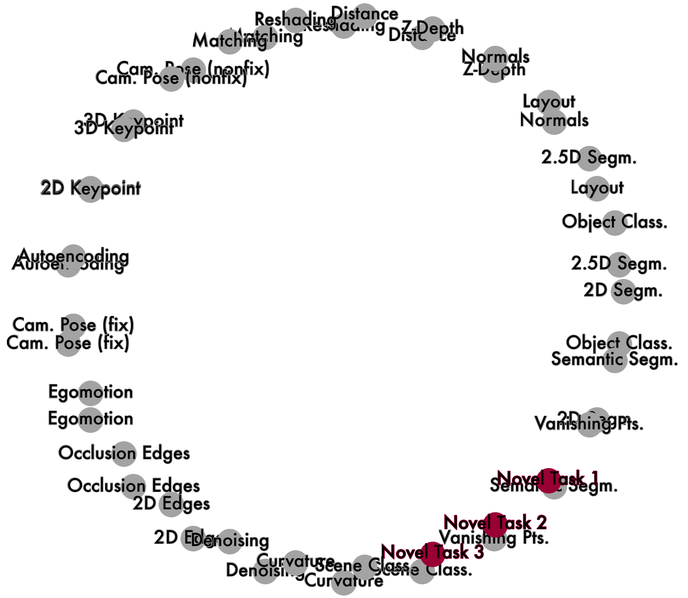
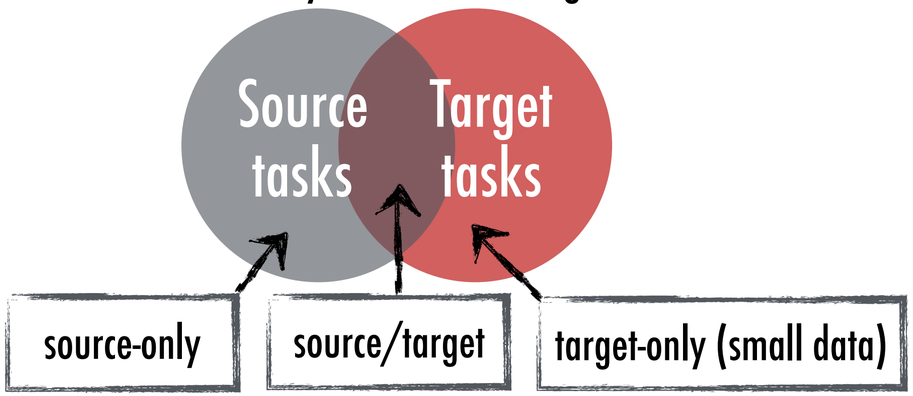
IV: Taxonomy Extraction



Dictionary= Sources ∪ Targets



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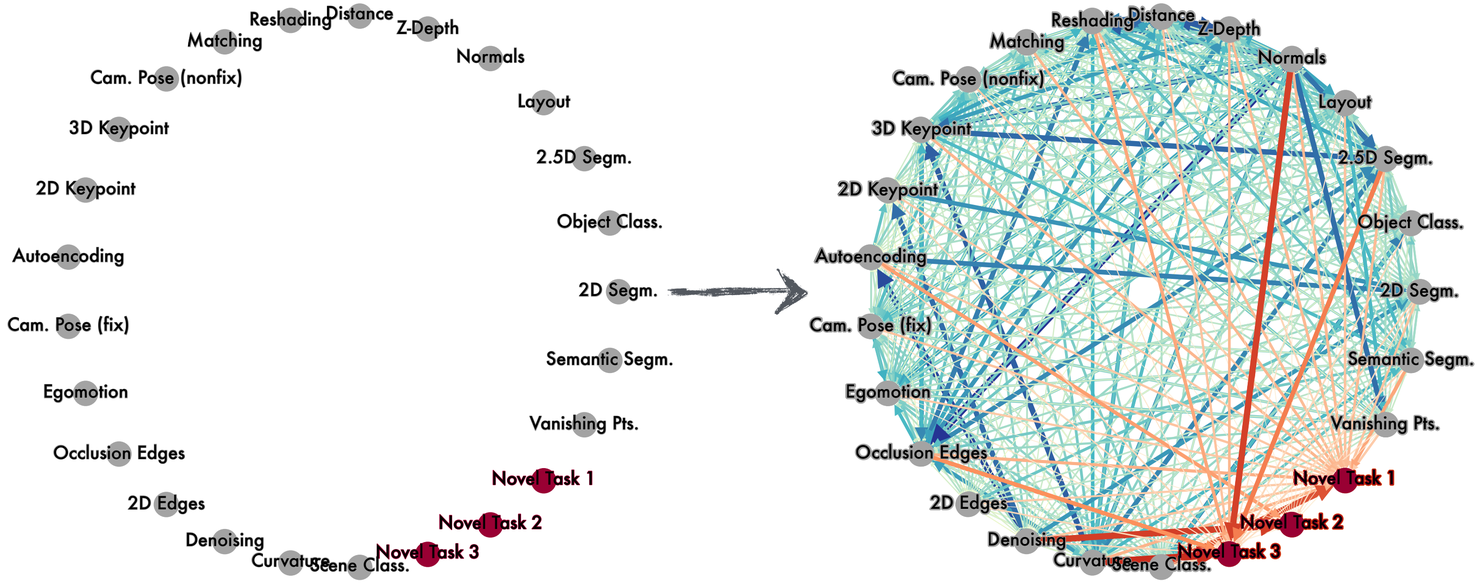
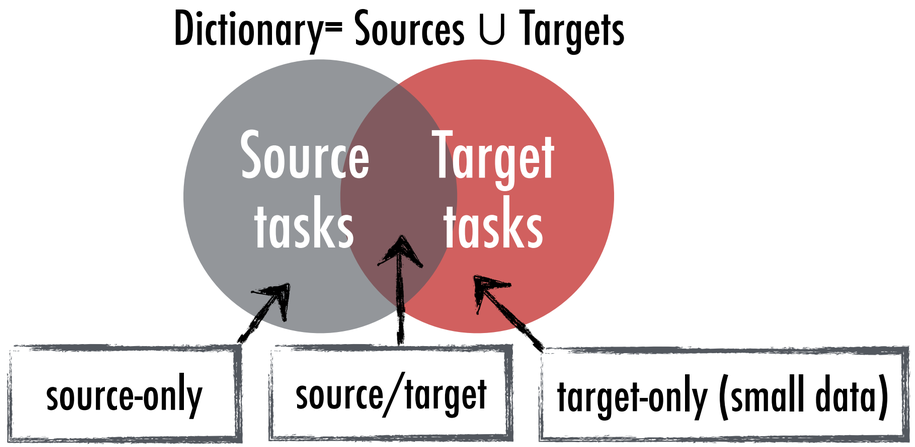
IV: Taxonomy Extraction





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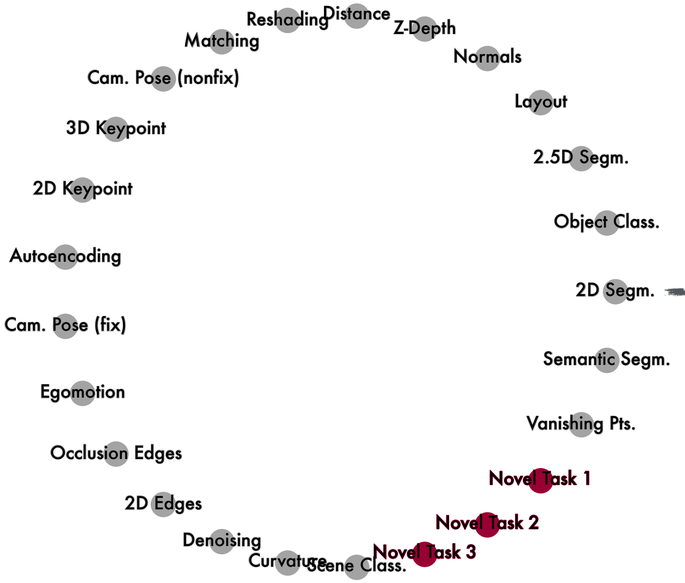
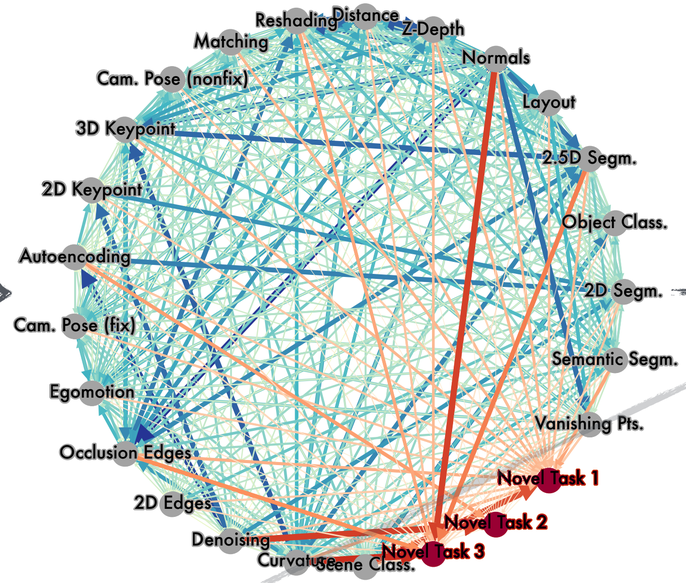
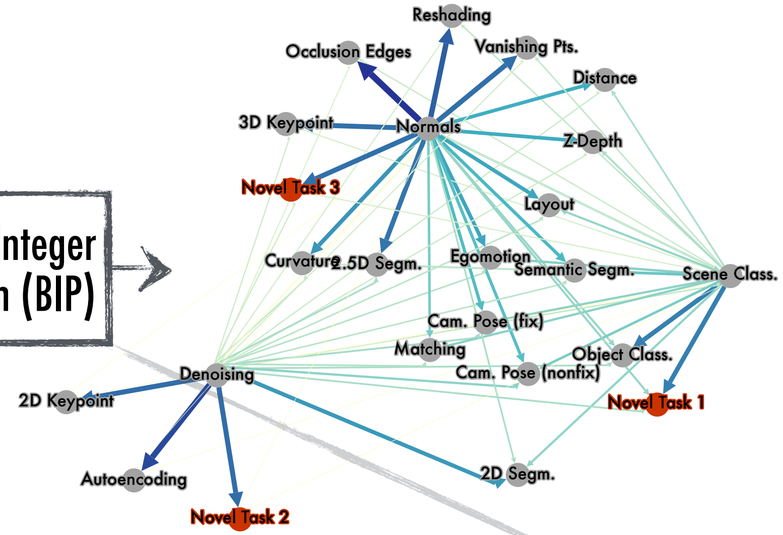
IV: Taxonomy Extraction





Binary Integer Program (BIP)



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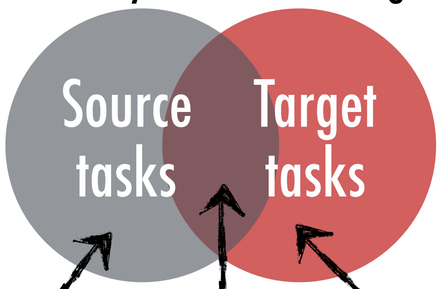
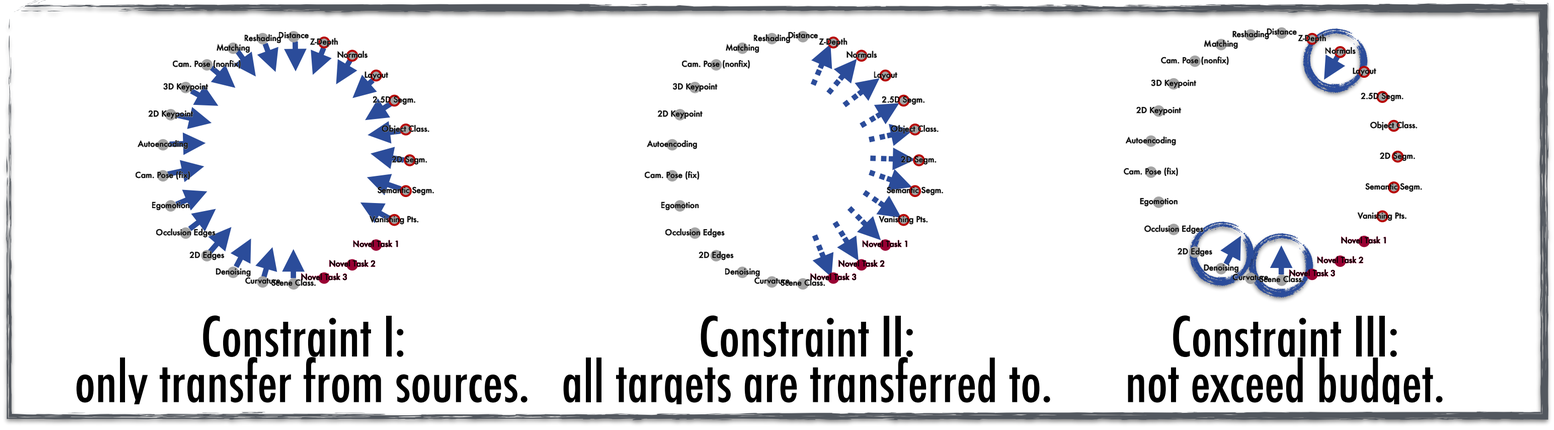


source-only | source/target | target-only (small data)



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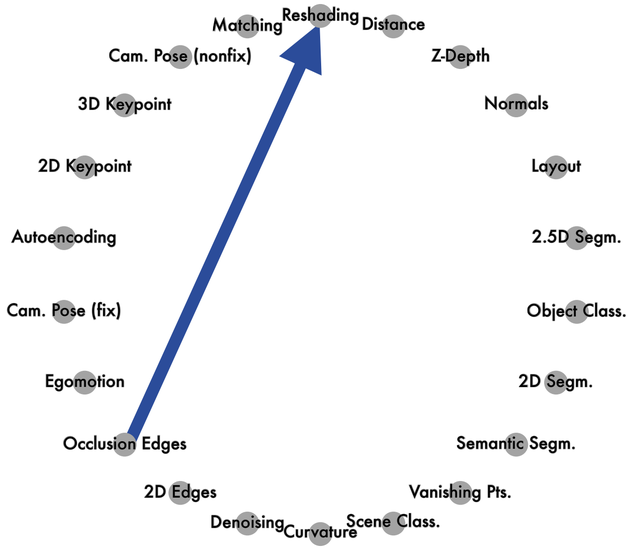
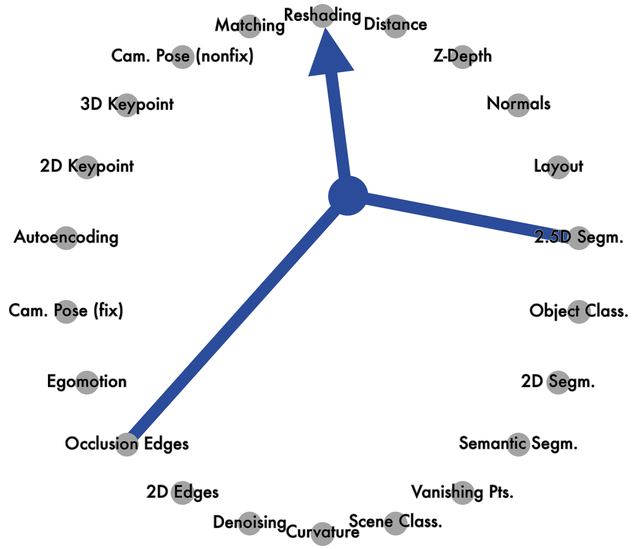
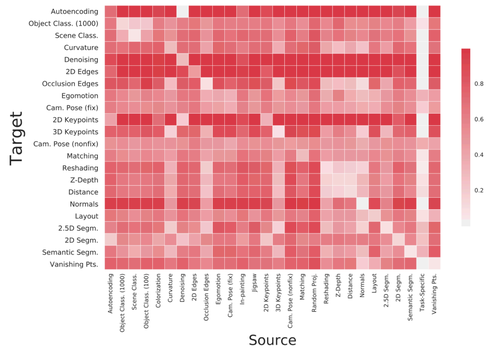
Higher Order Transfers

1st order transfer



2nd order transfer





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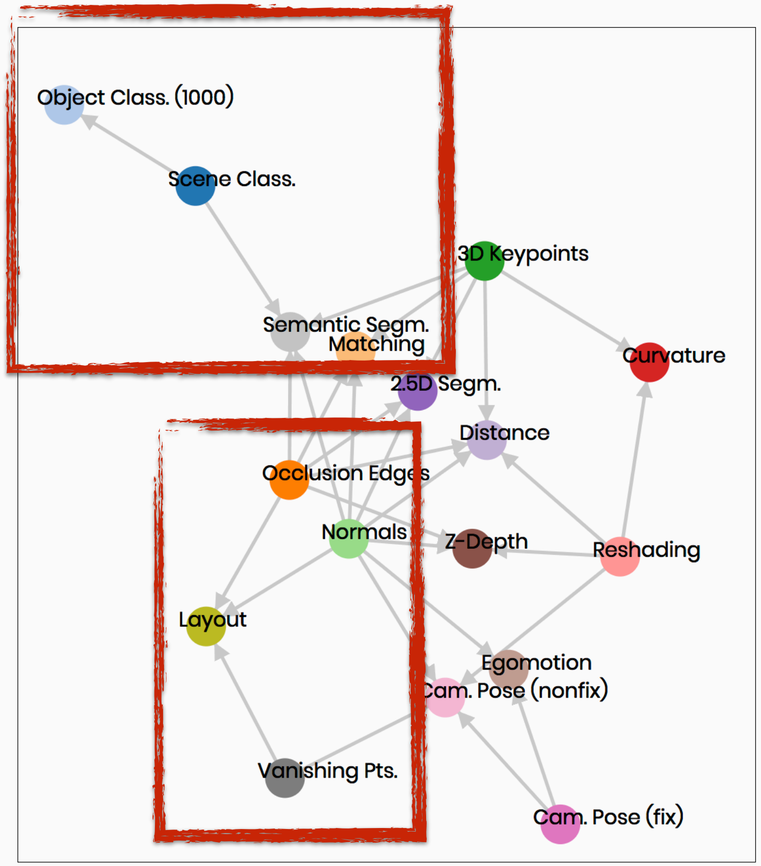
Experimental Results

- 26 Task-Specific Networks
- 3000 Transfer Networks
- 47,829 GPU hours 
- Transfers training data: 8x-120x less than task-specific

A Taxonomy

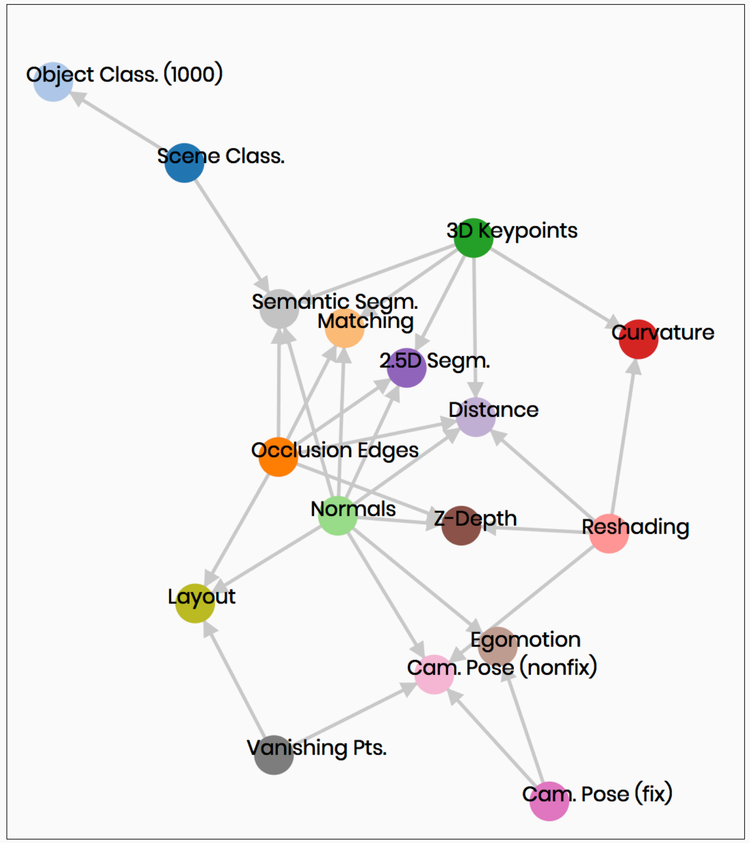


Target-only: Semantic Segmentation, Layout, Egomotion, 3D Curvature.

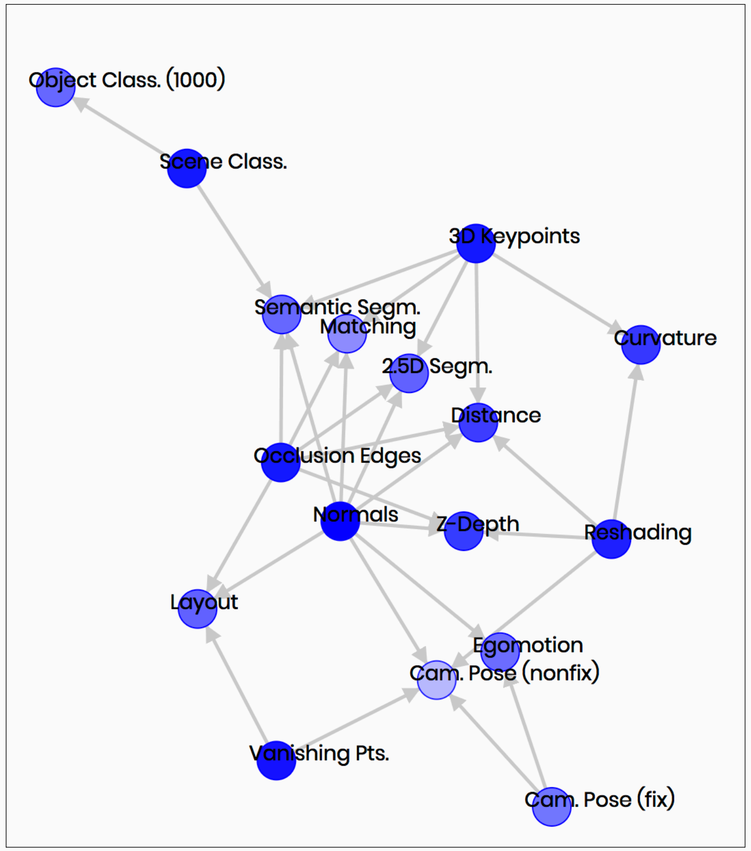
Source/Target: Depth, Occlusion Edges, Scene Classification, Normals, Camera Pose (non-fix), 3D Keypoint, Object Classification, Z-depth, Reshading, 3D Segmentation, Vanishing-Point, Camera pose (fix), Matching.

Source-only: Jigsaw, Colorization, Autoencoding, 2D edges, 2D edges, 2D keypoints, Denoising.

A Taxonomy



Gain



Gain: how much gained by transferring. (Win rate against a network trained from scratch using transfer data)

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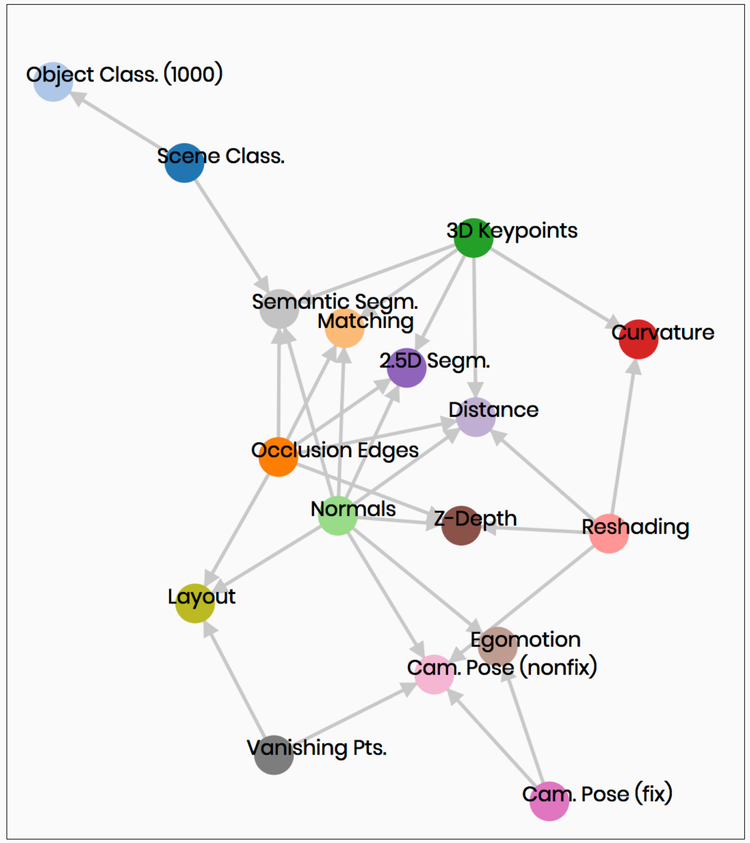
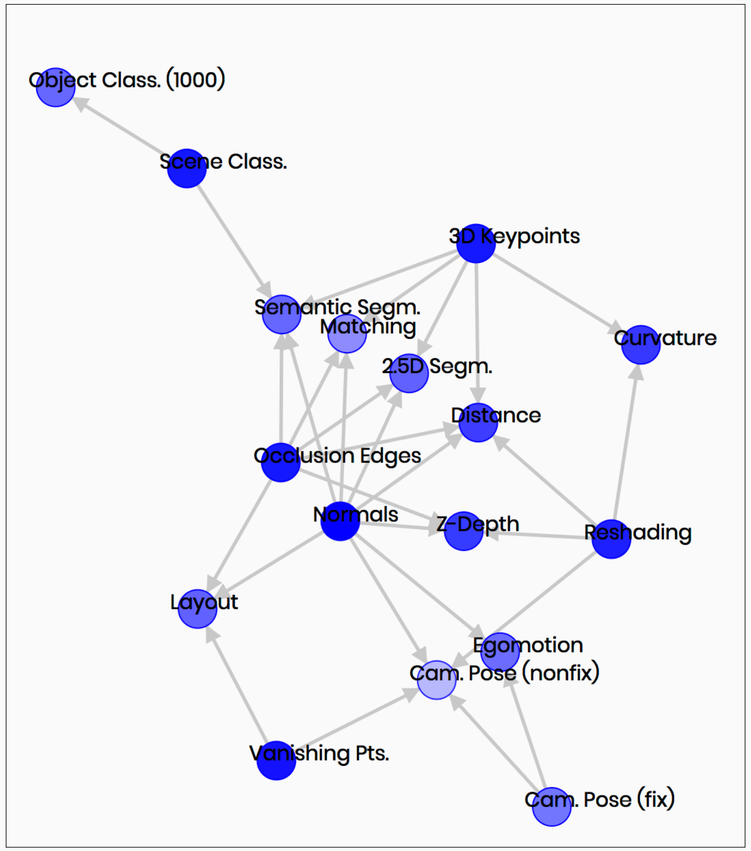
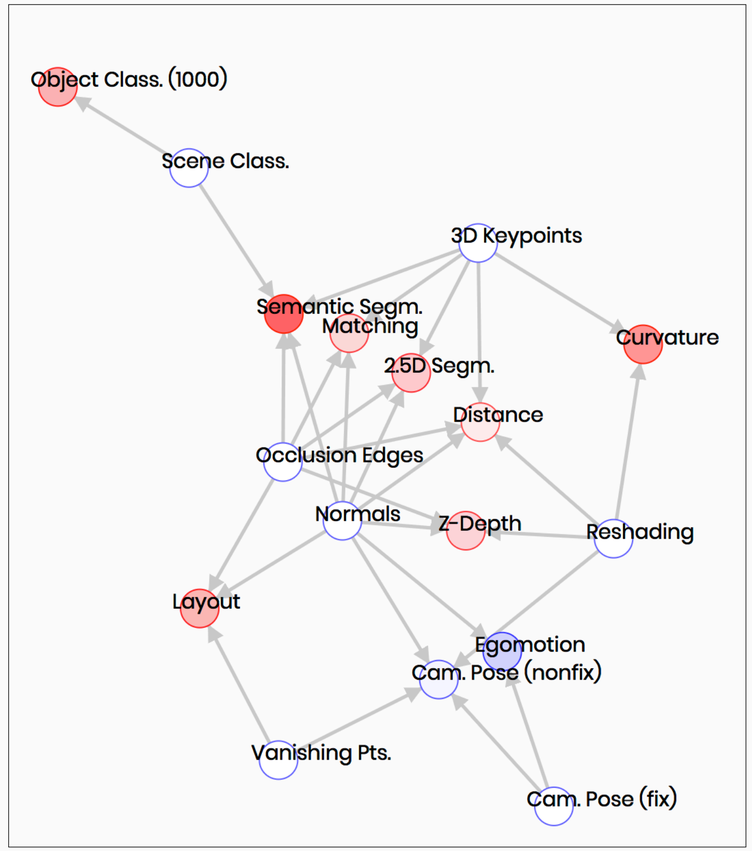
A Taxonomy



Gain



Quality



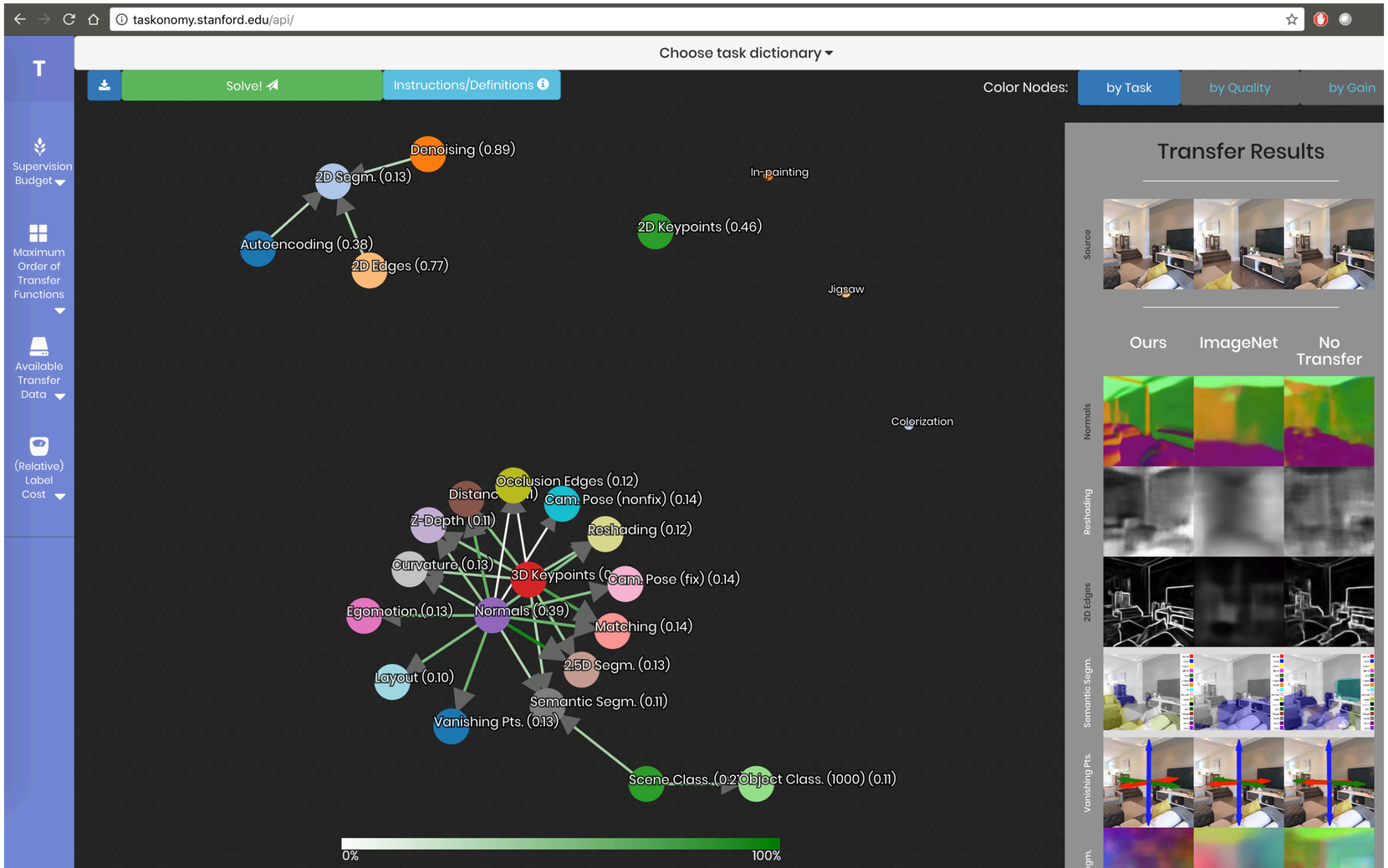
Gain: how much gained by transferring. (Win rate against a network trained from scratch using transfer data)

Quality: how close to gold-standard task-specific networks. (win rate against a fully supervised network)

0% 50% 100%

Live Web API: http://taskonomy.vision/api/

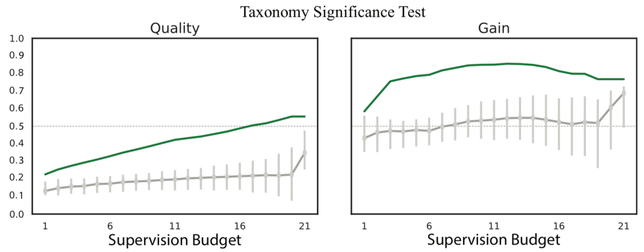
Run taskonomy with any arguments. See qualitative and quantitate results.



Experiments in paper/poster

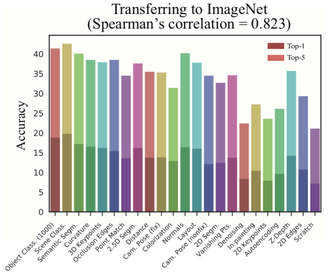
Experiments in paper/poster

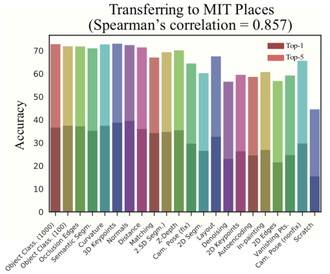
- Significance Test

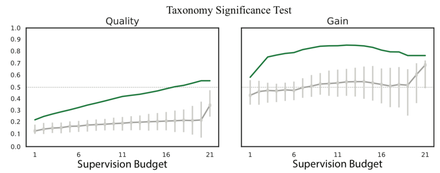


Experiments in paper/poster

- Significance Test
- Trends on ImageNet and MIT Places



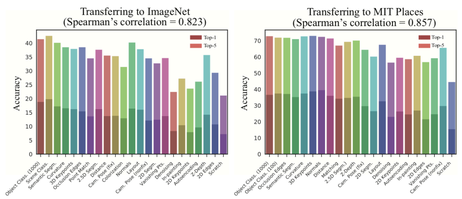


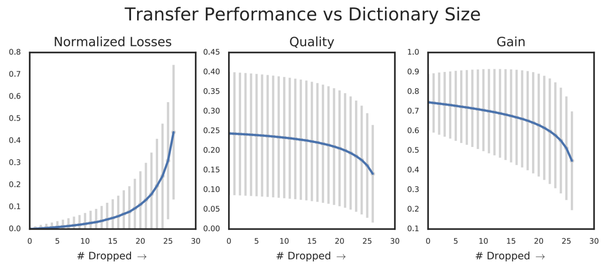


Zamir et al. Taskonomy 2018

Experiments in paper/poster

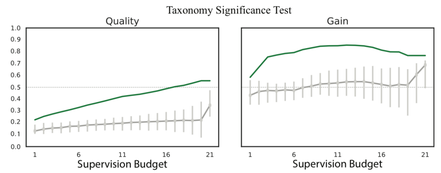
- Significance Test
- Trends on ImageNet and MIT Places
- Sensitivity to choice of dictionary

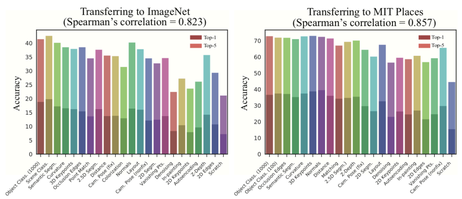


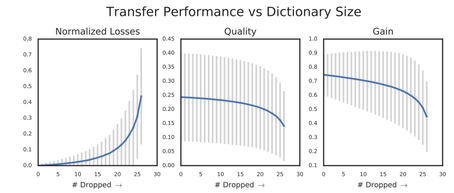


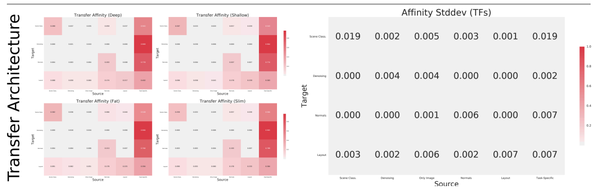
Experiments in paper/poster

- Significance Test
- Trends on ImageNet and MIT Places
- Sensitivity to choice of dictionary
- Architecture dependence



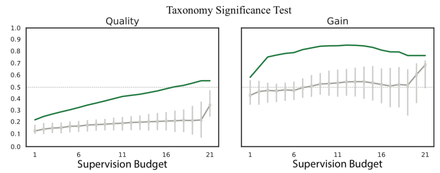


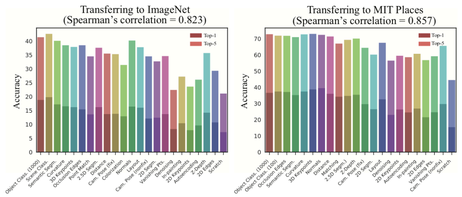


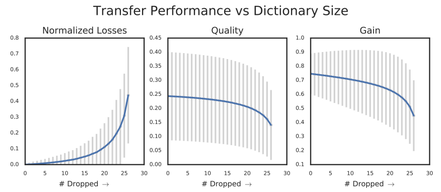


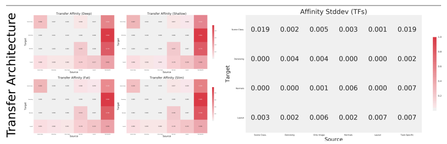
Experiments in paper/poster

- Significance Test
- Trends on ImageNet and MIT Places
- Sensitivity to choice of dictionary
- Archiecture dependence
- Generalization to single out-of-dictionary tasks
  - Outperforming self-supervised, unsupervised, ImageNet-based baselines by large margin.





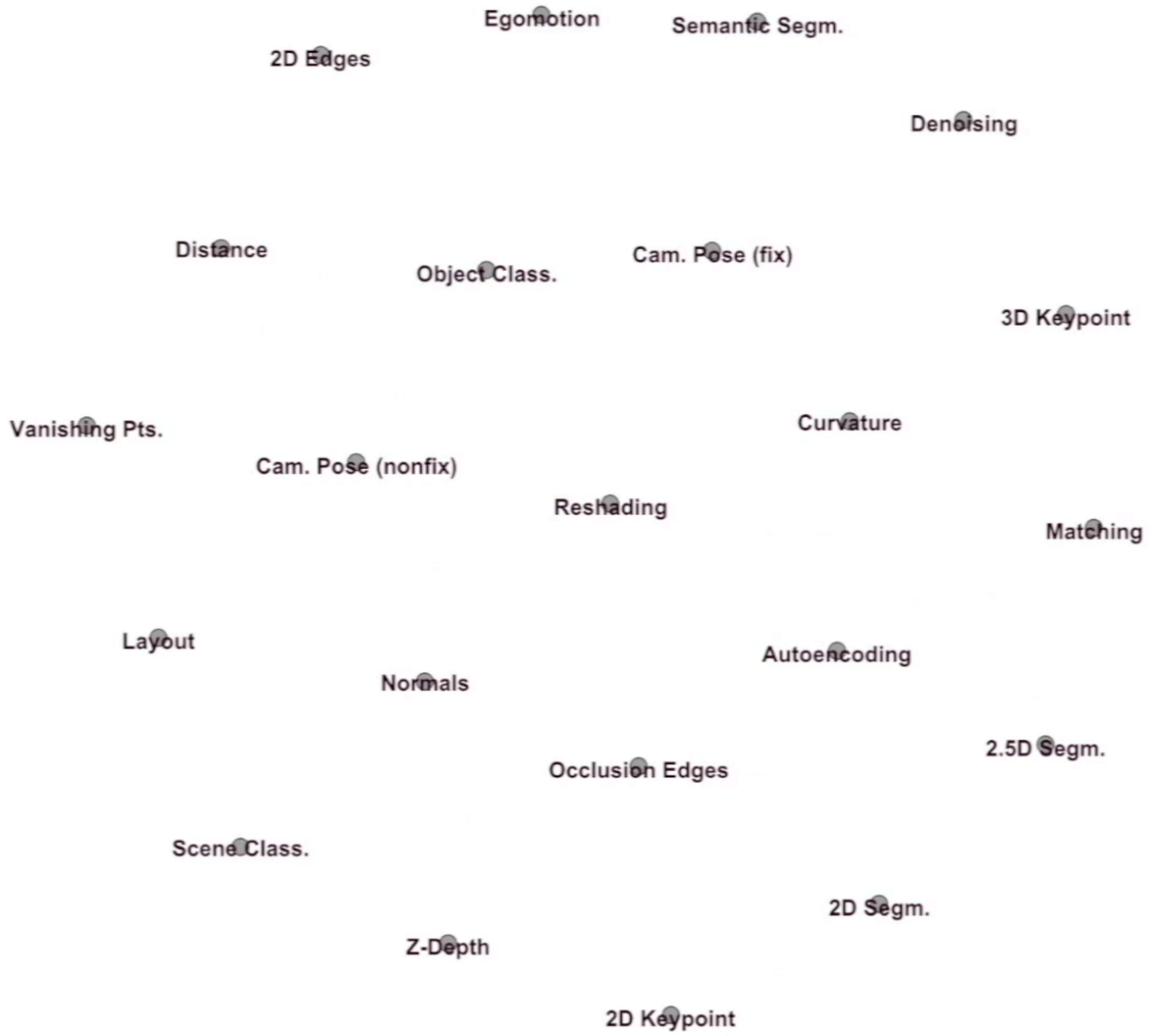


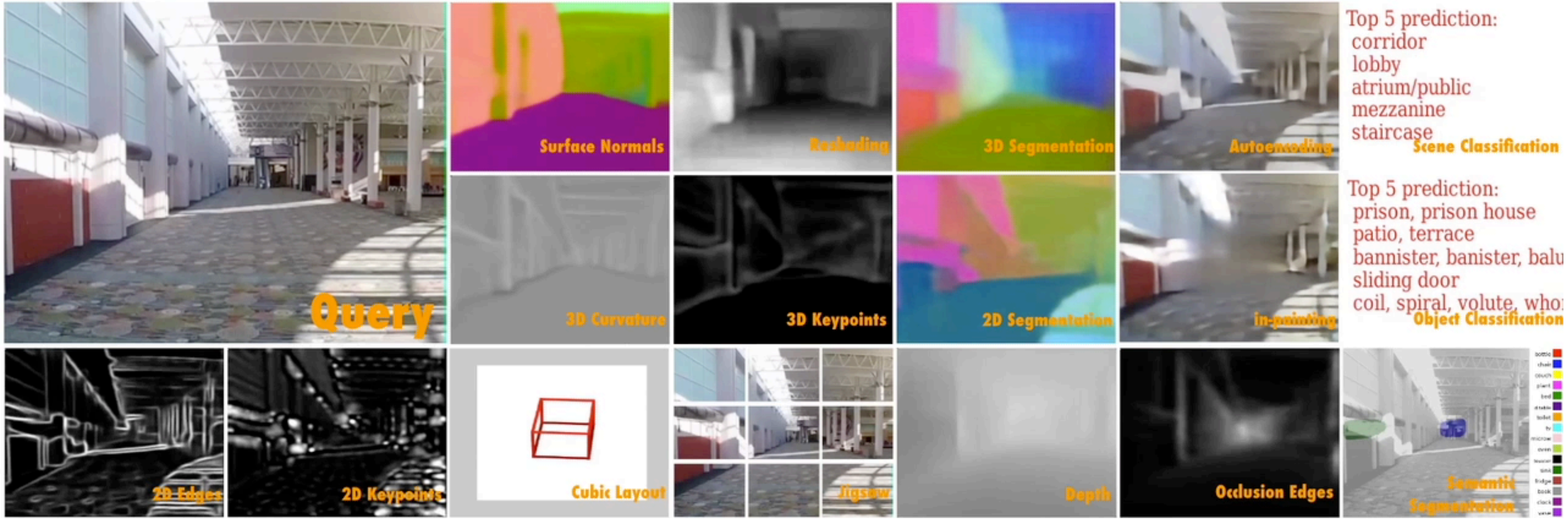


Task	scratch	ImageNet[51]	Wang,[96]	Agrawal,[1]	Zamir,[100]	Zhang,[103]	Noroozi,[68]	full sup.
Depth	88	88	93	89	88	84	86	43
	.03	.04	.04	.03	.04	.03	.03	**.02**
Scene Cls.	80	52	83	74	74	71	75	15
	3.30	2.76	3.56	3.15	3.17	3.09	3.19	**2.23**
Sem. Segm.	78	79	82	85	76	78	84	21
	1.74	1.88	1.92	1.80	1.85	1.74	1.71	**1.42**
Object Cls.	79	54	82	76	75	76	76	34
	4.08	3.57	4.27	3.99	3.98	4.00	3.97	**3.26**
Normals	97	98	98	98	98	97	97	6
	.22	.30	.34	.28	.28	.23	.24	**.12**
2.5D Segm.	80	93	92	89	90	84	87	40
	.21	.34	.34	.26	.29	.22	.24	**.16**
Occ. Edges	93	96	95	93	94	93	94	42
	.16	.19	.18	.17	.18	.16	.17	**.12**
Curvature	88	94	89	85	88	92	88	29
	.25	.28	.26	.25	.26	.26	.25	**.21**
Egomotion	79	78	83	77	76	74	71	59
	8.60	8.58	9.26	8.41	8.34	8.15	7.94	7.32
Layout	80	76	85	79	77	78	70	36
	.66	.66	.85	.65	.65	.62	.54	**.37**

Summary

- A striving step towards understanding the space of vision tasks.
- Treat tasks in concert, coming from a structured space, rather than isolated concepts.
- A fully computational framework.
- Transfer Learning. Generalist perception model.





Thank you!

http://taskonomy.stanford.edu/

Taskonomy: Disentangling Task Transfer Learning

Zamir, Sax*, Shen*, Guibas, Malik, Savarese