A Unified Framework for Learning and Processing Perceptual, Relational, and Meta Knowledge

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The “Vector Toolkit”

3 algorithms on **fixed-width vectors**

(Set of Vectors)

11011010111
00011010111

...  
10101100001

(Learn) → (Feature Hierarchy)

Encode

10101111101

(Vector encoded using features)

Encode

F12
F25
F37

(Predict) → (Likely reconstruction)

?101111?1??

(Vector with missing elements)

11011111101

(Likely reconstruction)
Vector Toolkit example

Animal Dataset (from UCI)

<table>
<thead>
<tr>
<th>Animal</th>
<th>hair</th>
<th>feathers</th>
<th>eggs</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aardvark</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Antelope</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Worm</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Wren</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Bat</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

(New Animal)

F72 (= “Mammal”)
“Airborne”

(Actually, it's a concept lattice)

(AAnimal with some unknown properties)

Likely reconstruction: Predict hairless)

Dodo
Can Learn Many Feature Hierarchies

Animal Vectors

Learn

Animal Taxonomy

Plant Vectors

Learn

Plant Taxonomy

16x16 Image Patches

Learn

Visual Feature Hierarchy For 16x16

32x32 Image Patches

Learn

Visual Feature Hierarchy For 32x32

How is Animal Taxonomy like Plant Taxonomy? Can we generalize knowledge about Image Patches?
A “Meta” Feature Hierarchy?

Use the Vector Tookit…

(Input “Vectors”)

Animal Taxonomy

Plant Taxonomy

Visual Feature Hierarchy For 16x16

Visual Feature Hierarchy For 32x32

Learn

“Feature Hierarchy” Feature Hierarchy

Feature Hierarchy for Feature Hierarchies

PARTIAL
Visual Feature Hierarchy For 64x64

(“Vector” with missing elements)

Predict

COMPLETE
Visual Feature Hierarchy For 64x64
A “Meta” Feature Hierarchy?

Vector Toolkit requires \textit{vectors}

Feature Hierarchies are \textit{structures}
Transform Feature-Hierarchies into Vectors

Partial Overlap in vectors iff Partial Structural Overlap in Feature-Hierarchies

E.g., if there is a large partial isomorphism between animal taxonomy and plant taxonomy, then their vector representations will have many common elements (and vice versa).

Other approaches (Plate's HRRs, Socher's autoencoders, Bag of Words) lack this property.

(See paper for details of Vectorize.)
Simple Demo
Process Finds Structure Similarity in (Object-level) Feature-Hierarchies

Animal Vectors

```
11011010111
00011010111
10101100001
```

“Zanimal” Vectors

```
11011010111
00011010111
10101100001
```

Congressional voting Vectors (from UCI)

```
111011010111
000111010111
101011001001
```

Learn

Animal Taxonomy

Vectorize

(Animal Tax. as Vector)

```
1001110....11011
```

“Zanimal” Taxonomy

Vectorize

(Zanimal Tax. Vector)

```
0100110....11001
```

Learn

“Congress” Feature Hierarchy

Vectorize

(Congress F.H. Vector)

```
1100000....01001
1100000....01001
1001110....11011
0100110....11001
```

“Feature Hierarchy” Feature Hierarchy

(Fongress, Zongress, and Fanimal F.H. Vectors)
Simple Demo
A Peek Under The Hood

Actual Animal Taxonomy (partial)

Actual Fanimal Taxonomy (partial)
Simple Demo
A Peek Under The Hood

Actual Congress Feature Hierarchy (partial)

The “Meta” Feature-Hierarchy (partial)
Discussion

Next Steps: Potential Uses of “Meta” Feature Hierarchies

- Transfer between domains
  - Learn about 64x64 image patches if 32x32 and 16x16 are already learned
  - Use **Encode** and **Predict** to make inferences for new domains
- Discover translation invariance in images
  - Feature hierarchy for top-left of image is structurally similar to bottom-right