Life-long Learning Perception using Cloud Database Technology

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Motivation

Identify specific objects of interest in sensor range.

- Describe objects by attributes instead of classes
- Learn objects over time
- Integrate new perception approaches over time
- Accommodate various sensor modalities
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Distributed Robot Perception Database

Extend perception system and object database over time and share it among robots.
Perception Classifier Cascades

Find a red apple.

Candidates

apple

color:red

Matches?

Result

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Motivation
Perception Database
Evaluation
Conclusion

Architecture

Classifiers
Base
SURF
Color
Haar
VFH
Shape
Attribute
pepper
color:red
color:yellow
apple
Meta

Data
Objects
Descriptors
Attributes
Queries

Query: {color : red, apple}

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## Perception Database Requirements

<table>
<thead>
<tr>
<th>Flexible Data Structures</th>
<th></th>
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Perception Database Requirements

**Flexible Data Structures**
- varying/evolving data structures

**Data Management**
- unified storage architecture
- replication, backup and restore

**Flexible and Efficient Retrieval**
- query for specific data
- low-overhead retrieval of diverse and large data

**MongoDB**, the document-oriented, schema-less database, is particularly well-suited to fulfill these criteria.
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- Motivation
- Perception Database
- Evaluation
- Conclusion

MongoDB and its Building Blocks

**Document-oriented**
- Grouped key-value pairs

**Schema-less**
- No declaration or enforcement of particular structure by DB

**Collections**
- Similarly structured documents
- Indexing reference frame

**Queries**
- JavaScript based query language
- Select based on document fields

```json
{ // attributes/classifiers
   // for specific object
   "_id" : ObjectId("50e..."),
   "data_id" : "apple_1_l_10_c",
   "scene_id" : "apple_1_l_10"
   "attributes" : {
      "apple" : true,
      "color" : "red"
   }
   "classifiers" :
   ["SIFT", "SURF", "Gabor",
    "Haar", "Color", "VFH" ...]
}

{ // classifier info excerpt
   // for attribute doc
   "_id" : ObjectId("52..."),
   "data_id" : "apple_1_l_10_c",
   "VFH" : {
      "model_file" : "apple_1_l_10_c_vfh.txt",
      "extract_time" : 20
   },
   // [...]
}
```
MongoDB in our Perception System

Scenes

Objects

Raw Data

- Image, Point
- Cloud, ...

Classifiers

- SIFT, VFH, ...

Attributes

- attributes: apple, color:red
- classifiers: sift, vfh, ...

Data Sharing

mongoDB

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Query Example

\[ Q = \{ \text{color : red, cup} \} \]
Query Example

\[ C^D_q = D.\text{classifiers}, \]
\[ \text{where } q \in D.\text{attributes} \]

\[ C_q = \bigcap_{C^D_q \neq \emptyset} C^D_q \]

```javascript
const docs = db.attributes.aggregate(
  {$match: { "attributes.color": "red"}},
  {$project: {classifiers: 1}},
  {$group: {_id: "$classifiers"}})

set_intersect(docs, "classifiers");
```
Query Example

\[ O_q = C_q(\text{input}) \]
\[ O = \bigcap_{q \in Q} O_q \]

- Apply classifiers
- Filter through cascade
Why a Cloud Database?

Flexible Data Structures

- Easily accommodate various data types
- Quickly grow w/o tedious specification

Query Capabilities

- Formulate queries deep into data structures
- Major benefit over traditional file system storage

Distributed Data

- Replicate for off-line training
- Quick boot-strapping for new robots/methods
- Sharding for multi-host robots
Full Retraining
Full Retraining

Gabor training magnified 4x

- Time [ms]
- # of iterations
- DB Read
- DB Write
- Training

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Conclusion and Questions

Cloud database for perception which is extensible in terms of known objects and perception methods.

- Attribute-based perception
- Increasing number of objects
- Evolve perception methods
- Flexible storage w/ MongoDB
- Capable query features
- Share data among robots

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