

# Pattern Recognition Lecture

## Summary, Applications, and Conclusions

Prof. Dr. Marcin Grzegorzek

Research Group for Pattern Recognition  
Institute for Vision and Graphics  
University of Siegen, Germany



# Topics

Introduction

Research  
Overview

Object  
Recognition

Conclusions

Date	No	Topic
17/04	PR01	Introduction and Outline
18/04	PR02	Feature Generation
02/05	PR03	Feature Selection
08/05	PR04	Linear Classifiers
15/05	PR05	Bayes Decision Theory
05/06	PR06	Context-Dependent Classification
06/06	PR07	Clustering Basics
26/06	PR08	Sequential Clustering
03/07	PR09	Hierarchical Clustering
10/07	PR10	Summary, Applications, and Conclusions

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## **Adaptive Learning of Context for Pattern Recognition**

# Overview

Introduction

Research  
Overview

Object  
Recognition

Conclusions

- 1 Introduction
- 2 Research Overview
- 3 Object Recognition
- 4 Conclusions

# Overview

## Introduction

Research  
Overview

Object  
Recognition

Conclusions

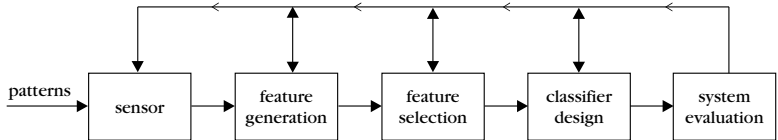
### 1 Introduction

### 2 Research Overview

### 3 Object Recognition

### 4 Conclusions

# Basic Stages of Pattern Analysis



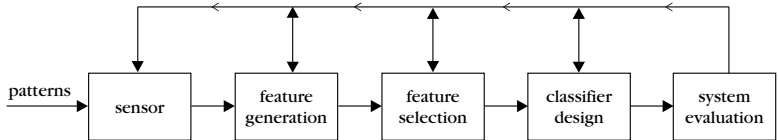
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Basic Stages of Pattern Analysis



- Adaptive Runtime Optimisation

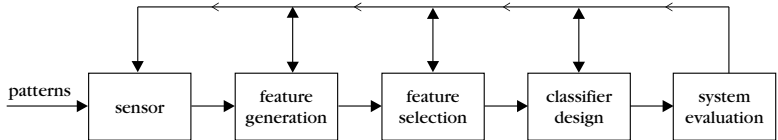
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Basic Stages of Pattern Analysis



- Adaptive Runtime Optimisation
- Integration of Background Knowledge

Introduction

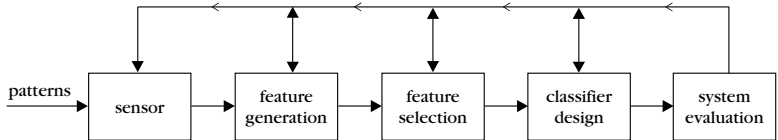
Research  
Overview

Object  
Recognition

Conclusions



# Basic Stages of Pattern Analysis



- **Adaptive Runtime Optimisation**
- Integration of Background Knowledge

Introduction

Research  
Overview

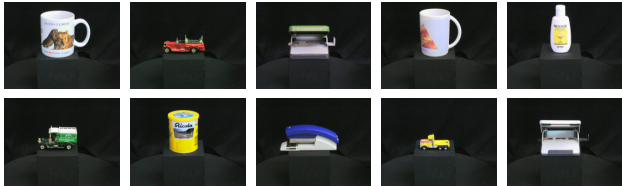
Object  
Recognition

Conclusions

# Scientific Methods for Pattern Recognition

## Example

- Generic Appearance-Based Statistical Object Recognition



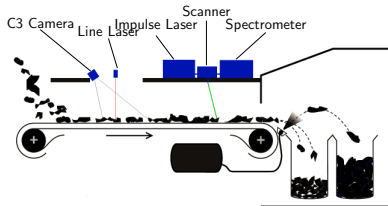
## Properties

- Generic Methodology without Fixing the Application
- Limited Robustness in Real-World Environments

# Industrial Systems for Pattern Recognition

## Example

- Automatic Sorting of Aluminium Alloys



## Properties

- Concrete Application Domain
- Problem-Specific Features
- Limited Portability

# Adaptive Learning for Pattern Recognition

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## **Development Phase**

- Generic System for Pattern Recognition
- Multiple Sensors, Features, and Classifiers

# Adaptive Learning for Pattern Recognition

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## **Development Phase**

- Generic System for Pattern Recognition
- Multiple Sensors, Features, and Classifiers

## **Supervision Phase**

- Application for a Concrete Task
- Labelling of Misclassified Patterns by a Supervisor
- Adaptive Optimisation of the Processing Chain

# Adaptive Learning for Pattern Recognition

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## **Development Phase**

- Generic System for Pattern Recognition
- Multiple Sensors, Features, and Classifiers

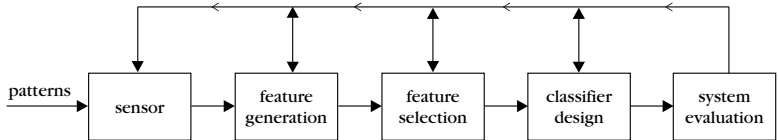
## **Supervision Phase**

- Application for a Concrete Task
- Labelling of Misclassified Patterns by a Supervisor
- Adaptive Optimisation of the Processing Chain

## **Recognition Phase**

- Further Application without Supervision

# Basic Stages of Pattern Analysis



- Adaptive Runtime Optimisation
- **Integration of Background Knowledge**

Introduction

Research  
Overview

Object  
Recognition

Conclusions

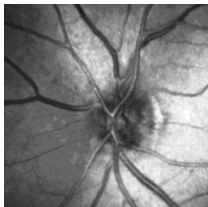
# Semantic Gap in Image Understanding

Introduction

Research  
Overview

Object  
Recognition

Conclusions



Background Knowledge

Semantic  
Image  
Interpretation



Semantic  
Image  
Description





# Overview

Introduction

**Research  
Overview**

Object  
Recognition

Conclusions

1 Introduction

2 **Research Overview**

3 Object Recognition

4 Conclusions

# Research Areas

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## Object Recognition

- Adaptive Learning of Context for Object Recognition
- Origin: Univ. of Erlangen-Nuremberg

## Multimedia Retrieval

- Adaptive Learning of User Preferences based on Relevance Feedback
- Origin: Queen Mary, University of London

## Image Understanding

- Integration of High-Level Background Knowledge from Ontologies into Low-Level Image Processing
- Origin: University of Koblenz-Landau

# Research Areas

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## ⇒ **Object Recognition**

- Adaptive Learning of Context for Object Recognition
- Origin: Univ. of Erlangen-Nuremberg

## **Multimedia Retrieval**

- Adaptive Learning of User Preferences based on Relevance Feedback
- Origin: Queen Mary, University of London

## **Image Understanding**

- Integration of High-Level Background Knowledge from Ontologies into Low-Level Image Processing
- Origin: University of Koblenz-Landau

# Research Areas

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## Object Recognition

- Adaptive Learning of Context for Object Recognition
- Origin: Univ. of Erlangen-Nuremberg

## ⇒ Multimedia Retrieval

- Adaptive Learning of User Preferences based on Relevance Feedback
- Origin: Queen Mary, University of London

## Image Understanding

- Integration of High-Level Background Knowledge from Ontologies into Low-Level Image Processing
- Origin: University of Koblenz-Landau

# Multimedia Content Management and Retrieval

Introduction

Research  
Overview

Object  
Recognition

Conclusions


K-Space Content Management and Retrieval System - Microsoft Internet Explorer

Address <http://138.37.33.138:9759/>

## K-Space Document Navigation

View	Document title & abstract	Transcode	Shot edition	Semantic annotation	Visual search
	<b>shakira legs dont lie</b> "Hips Don't Lie" is a Grammy Award-nominated Latin pop song performed by Colombian singer Shakira and Haitian rapper Wyclef Jean. The music video was direct...				
	<b>simone says nothing compares to you</b> "Nothing Compares To You" is a song written around 1984 or 1985 by Prince for The Family, a funk band created as an outlet to release more of his music. Five...				
	<b>lenny says baby one more time</b> Shot at Venice High School in California, the scenario begins with Spears in a particularly boring class right before the end of the day. Her assistant Falc...				

<http://138.37.33.138:9759 - View Document 'moloko sing it back...>



le songs, and its music video, popular on MTV is dancing and performing the song in a bright white ring alone in a metallic flapper dress, accompanied heup included Rob Hirst on drums, Peter Garnett on er to white room and singing a slow song about her the group of men dressed in black suits. Video from Düsseldorf, and Andi Toma, from Köln) who Journalist. Ministry of Defence and Tony Blair conference. Angela Merkel is joining the rally. n. Dual between Jan Ulrich and Lars Armstrong is

describes Ulrich with 12th stage: Kazakhstan cycl...

**News journal4**  
Schneider speaking with Romano Prodi in Berlin about the European Union Stability pact. They are standing in front of Brandenburg Gate in Berlin commenting i...

**News journal5**  
Ulrich Barth Deutsche Welle journalists speak about mobile phones market. Business news. Ericson

Start | 1:138.37.33.126 - m... | 2:138.37.33.126 - m... | K-Space Content Ma... | <http://138.37.33.1...> | images | Kspace\_system - Win... | 10:13 AM

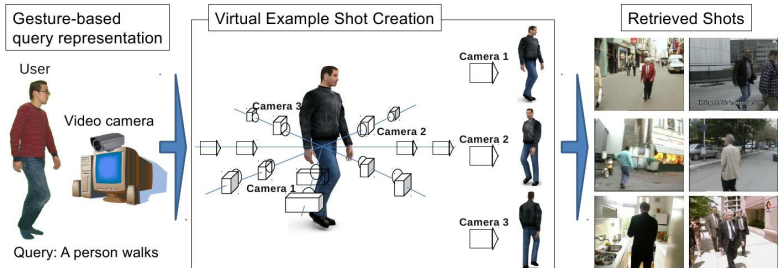
# Query by Virtual Gesture

Introduction

Research  
Overview

Object  
Recognition

Conclusions



- Background Knowledge Integration by Domain Ontology
- Adaptive Optimisation by Relevance Feedback

# Research Areas

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## Object Recognition

- Adaptive Learning of Context for Object Recognition
- Origin: Univ. of Erlangen-Nuremberg

## Multimedia Retrieval

- Adaptive Learning of User Preferences based on Relevance Feedback
- Origin: Queen Mary, University of London

## ⇒ Image Understanding

- Integration of High-Level Background Knowledge from Ontologies into Low-Level Image Processing
- Origin: University of Koblenz-Landau

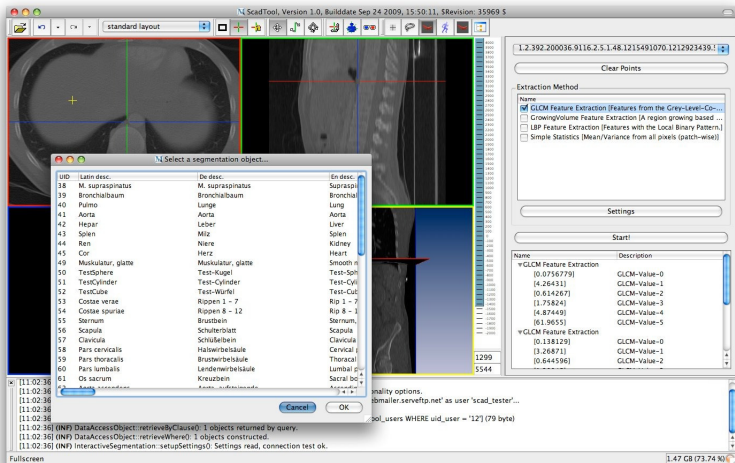
# Spatial Reasoning for Medical Image Classification

Introduction

Research  
Overview

Object  
Recognition

Conclusions





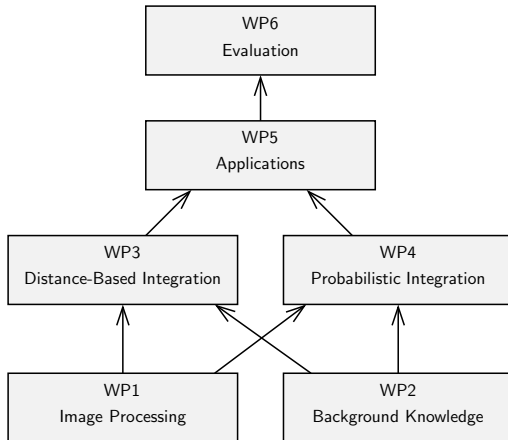
# Knowledge-Based Image Understanding

Introduction

Research  
Overview

Object  
Recognition

Conclusions



# Overview

Introduction

Research  
Overview

**Object  
Recognition**

Conclusions

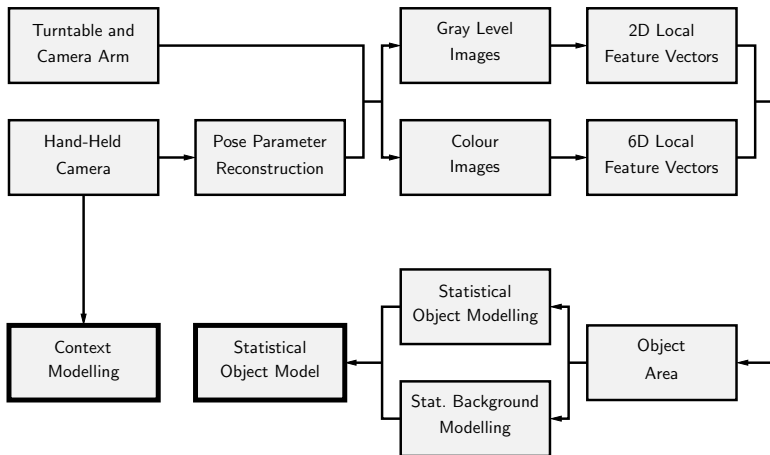
1 Introduction

2 Research Overview

3 Object Recognition

4 Conclusions

# Training Phase



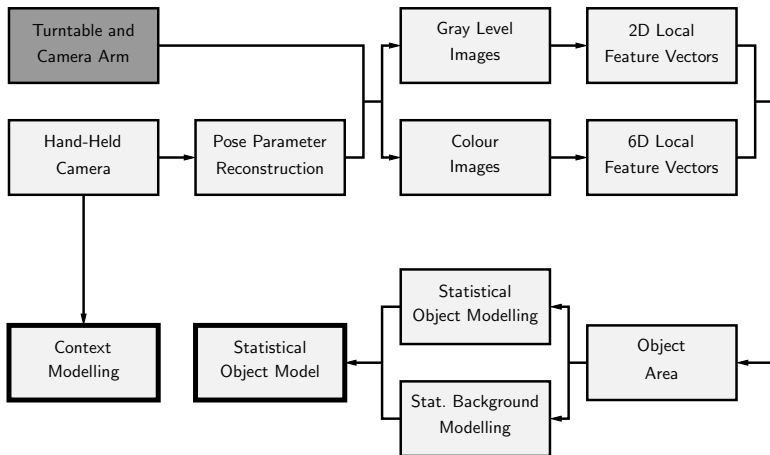
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Turntable and Camera Arm



Introduction

Research  
Overview

Object  
Recognition

Conclusions

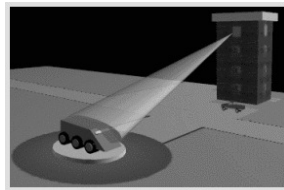
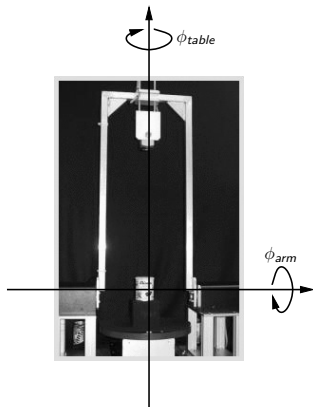
# Turntable and Camera Arm

Introduction

Research  
Overview

Object  
Recognition

Conclusions



Object poses  $(\phi_{\rho}, \mathbf{t}_{\rho})$  for all  $N_{\rho}$  training images  $\mathbf{f}_{\rho=1, \dots, N_{\rho}}$  are known.

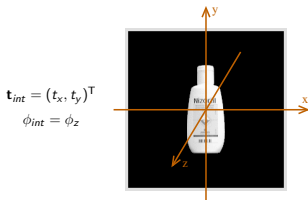
# Object Pose

Introduction

Research  
Overview

Object  
Recognition

Conclusions



$$\mathbf{t}_{int} = (t_x, t_y)^T$$

$$\phi_{int} = \phi_z$$

$$\mathbf{t} = (t_x, t_y, t_z)^T = (0, 0, 100)^T$$

$$\phi = (\phi_x, \phi_y, \phi_z)^T = (0, 0, 0)^T$$



$$\mathbf{t} = (50, 25, 100)^T$$

$$\phi = (0, 0, 0)^T$$



$$\mathbf{t} = (50, 25, 100)^T$$

$$\phi = (0, 0, -30)^T$$

$$t_{ext} = t_z$$

$$\phi_{ext} = (\phi_x, \phi_y)^T$$



$$\mathbf{t} = (0, 0, 100)^T$$

$$\phi = (22.5, 0, 0)^T$$



$$\mathbf{t} = (0, 0, 100)^T$$

$$\phi = (0, 45, 0)^T$$



$$\mathbf{t} = (0, 0, 80)^T$$

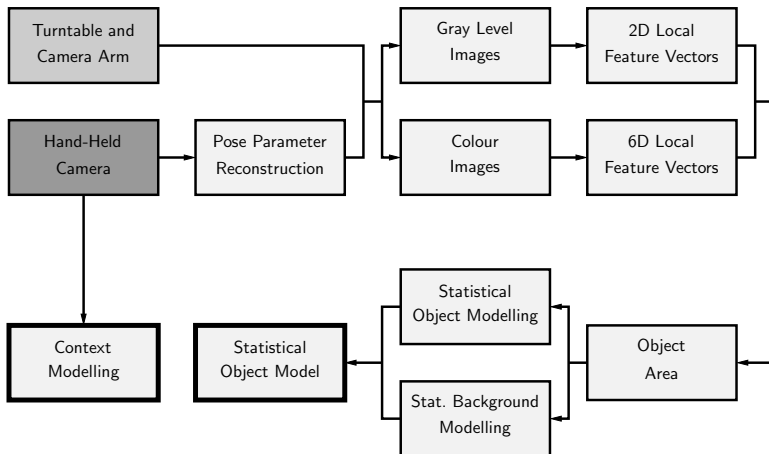
$$\phi = (0, 0, 0)^T$$

# Hand-Held Camera

Introduction  
Research  
Overview

Object  
Recognition

Conclusions



# Hand-Held Camera

Introduction

Research  
Overview

Object  
Recognition

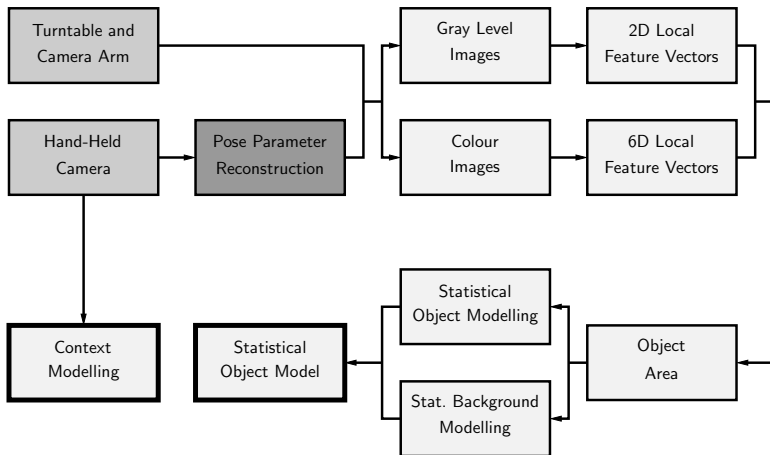
Conclusions



Object poses  $(\phi_\rho, \mathbf{t}_\rho)$  for the training images  $\mathbf{f}_\rho$  are unknown.



# Pose Parameter Reconstruction



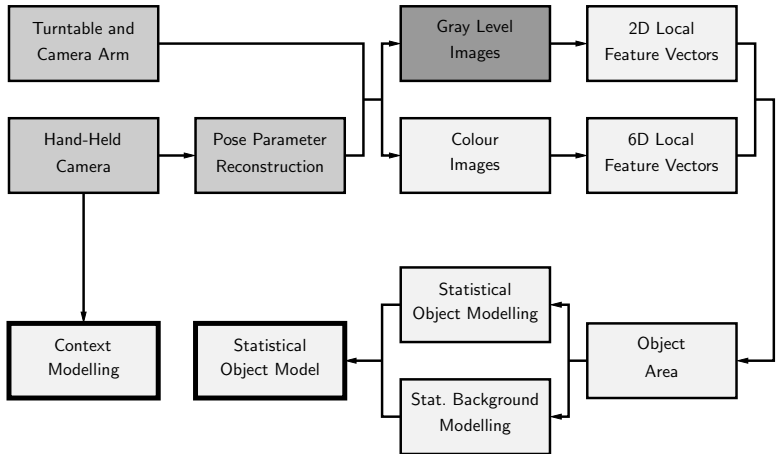
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Grey Level Images



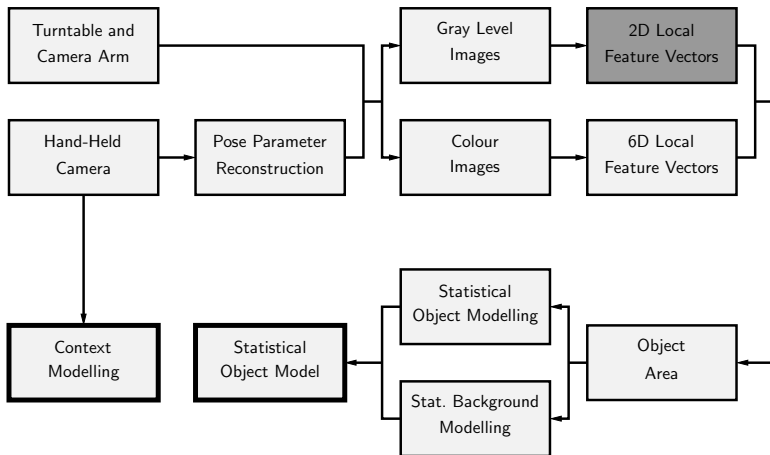
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# 2D Local Feature Vectors



Introduction

Research  
Overview

Object  
Recognition

Conclusions

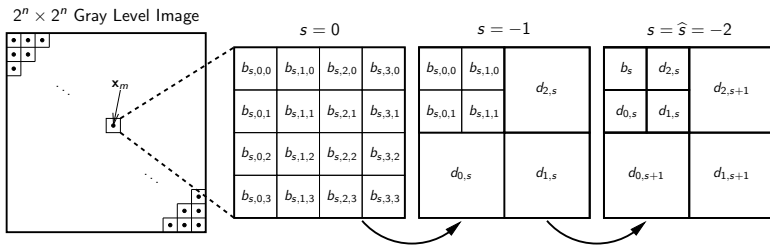
# 2D Feature Extraction with Wavelet Transform

Introduction

Research  
Overview

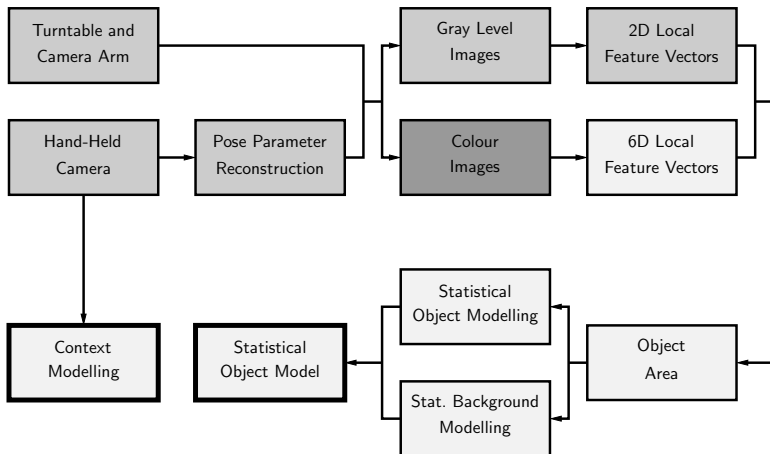
Object  
Recognition

Conclusions



$$\mathbf{c}_m = \mathbf{c}(\mathbf{x}_m) = \begin{pmatrix} c_{m,1} \\ c_{m,2} \end{pmatrix} = \begin{pmatrix} \ln(2^s |b_s|) \\ \ln[2^s (|d_{0,s}| + |d_{1,s}| + |d_{2,s}|)] \end{pmatrix}$$

# Colour Images



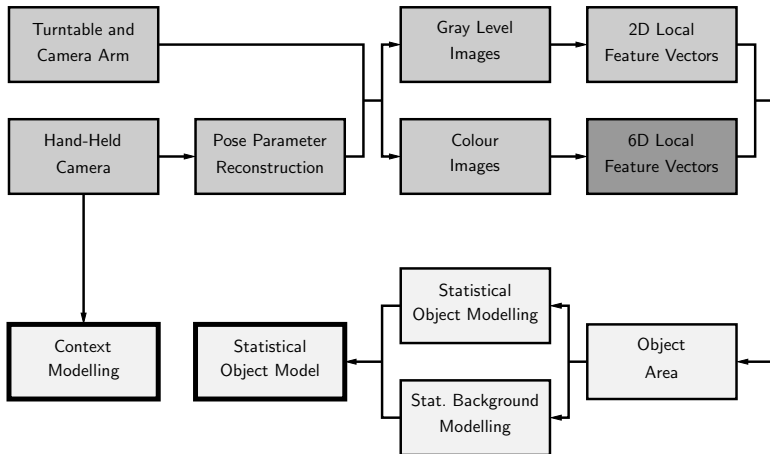
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# 6D Local Feature Vectors



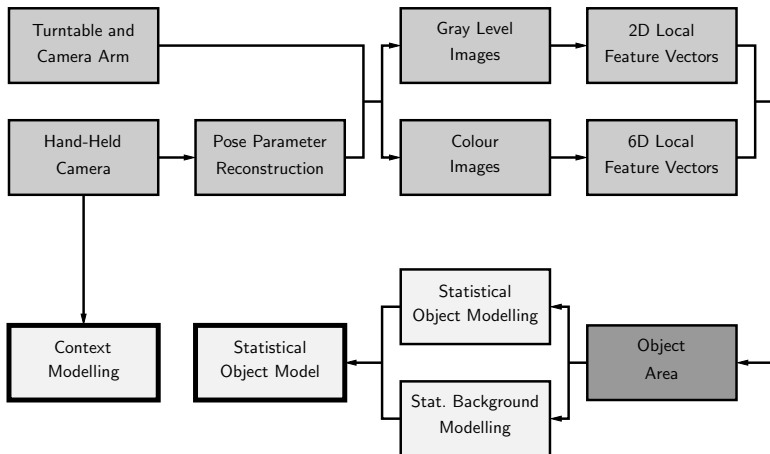
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Object Area



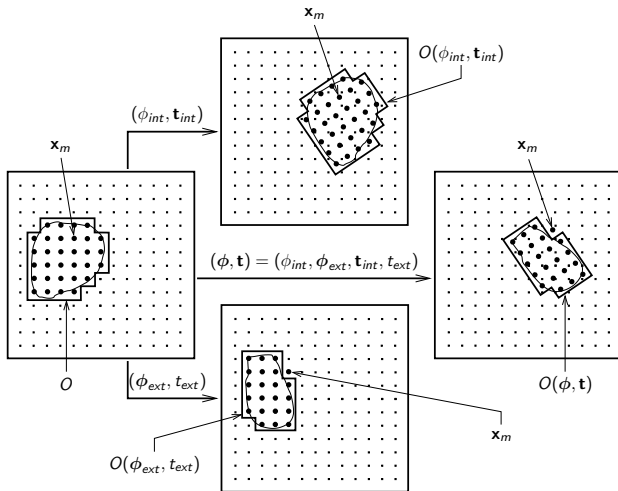
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Object Area $O = O(\phi, \mathbf{t})$



Introduction

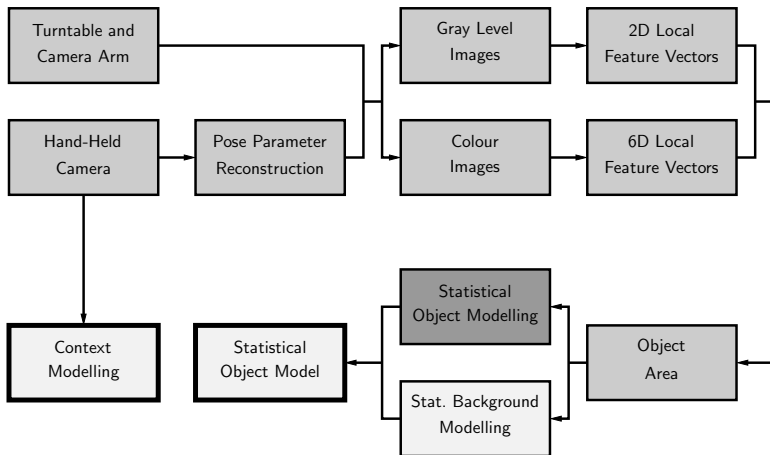
Research  
Overview

Object  
Recognition

Conclusions



# Statistical Object Modelling



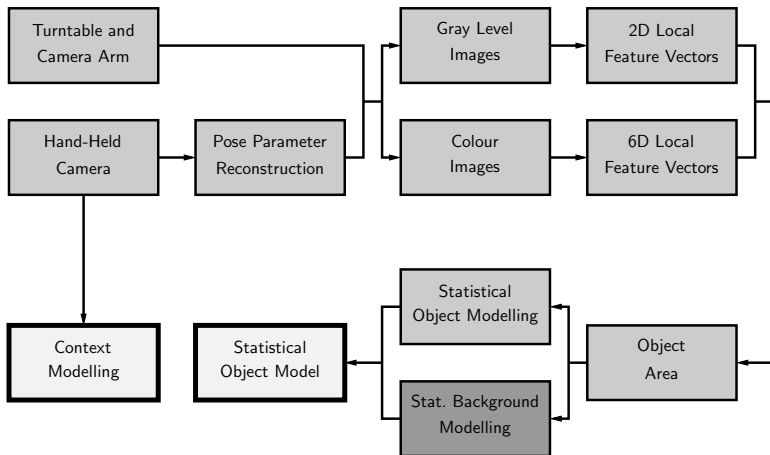
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Statistical Background Modelling



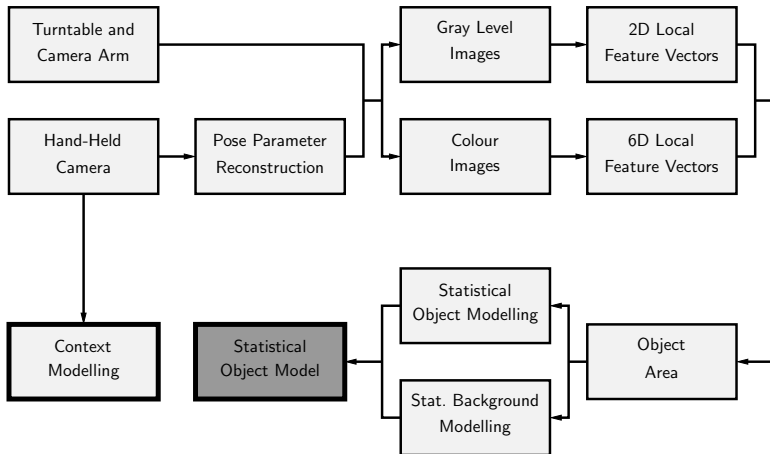
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Statistical Object Model



Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Statistical Object Model - Summary

Introduction

Research  
Overview

Object  
Recognition

Conclusions

$$\Omega_{\kappa} \longrightarrow \mathcal{M}_{\kappa} = \mathcal{M}_{\kappa}(\phi, \mathbf{t})$$

1. Object Area

$$O_{\kappa} = O_{\kappa}(\phi, \mathbf{t})$$

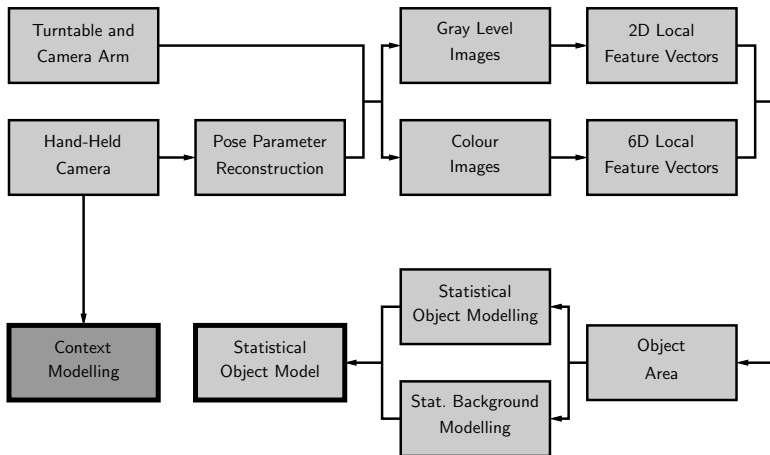
2. Densities for Object Features

$$p(\mathbf{c}_m) = p(\mathbf{c}_m | \mu_m, \sigma_m, \phi, \mathbf{t})$$

3. Densities for Background Features

$$p(\mathbf{c}_m) = p_b$$

# Context Modelling



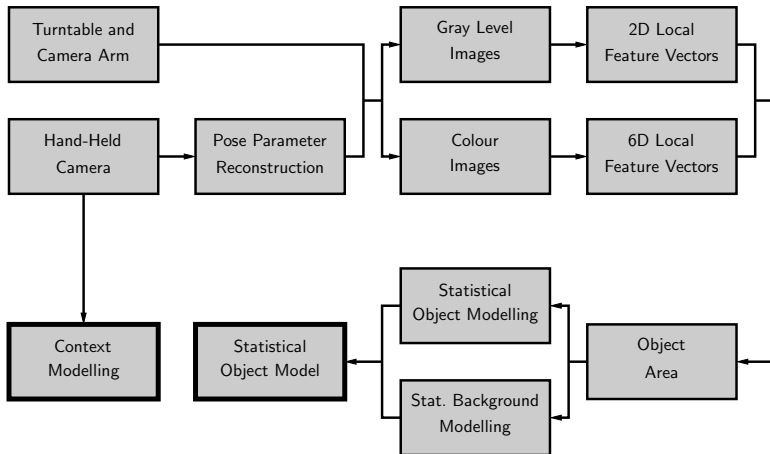
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Training Phase Completed



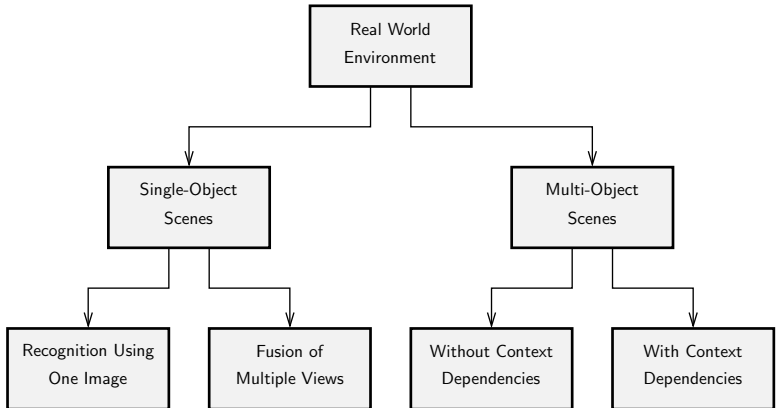
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Recognition Phase



Introduction

Research  
Overview

Object  
Recognition

Conclusions

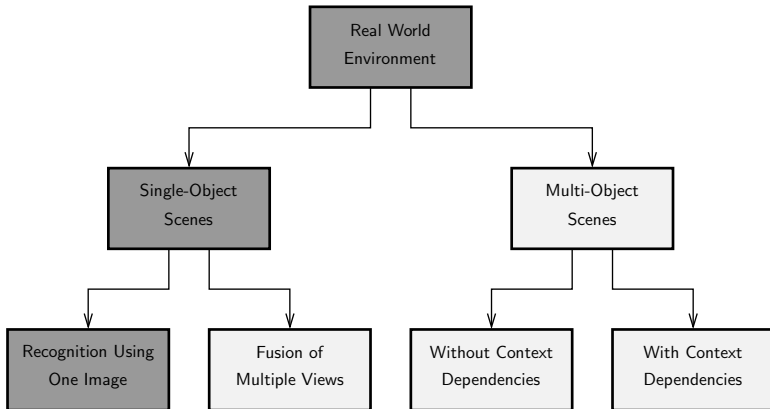
# Single-Object, One Image

Introduction

Research  
Overview

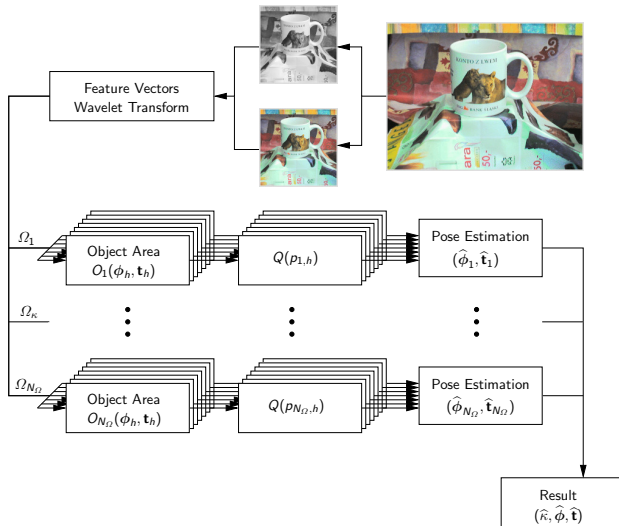
Object  
Recognition

Conclusions





# Classification and Localisation Algorithm



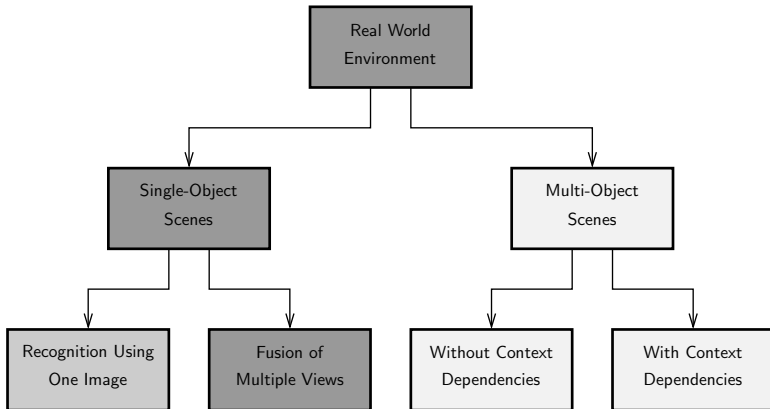
Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Single-Object, Multiple Views



Introduction

Research  
Overview

Object  
Recognition

Conclusions

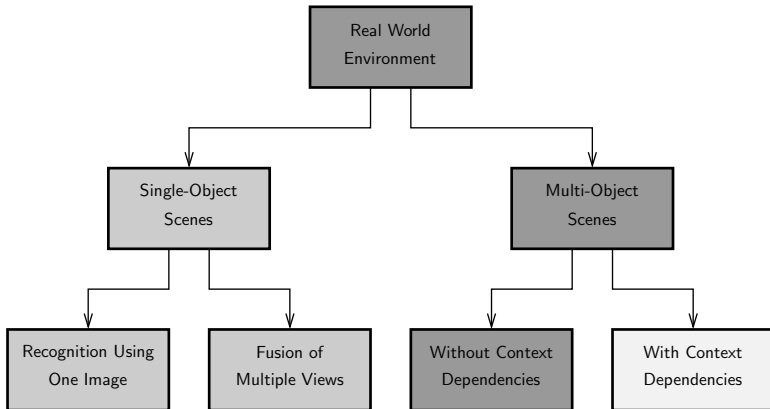
# Multi-Object Scenes without Context

Introduction

Research  
Overview

Object  
Recognition

Conclusions



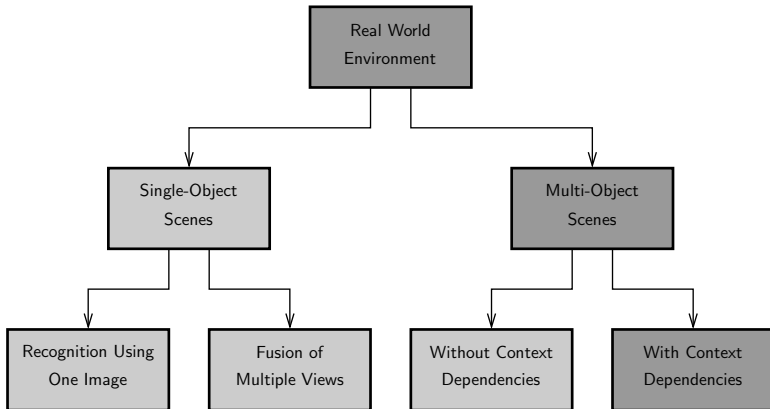
# Multi-Object Scenes with Context

Introduction

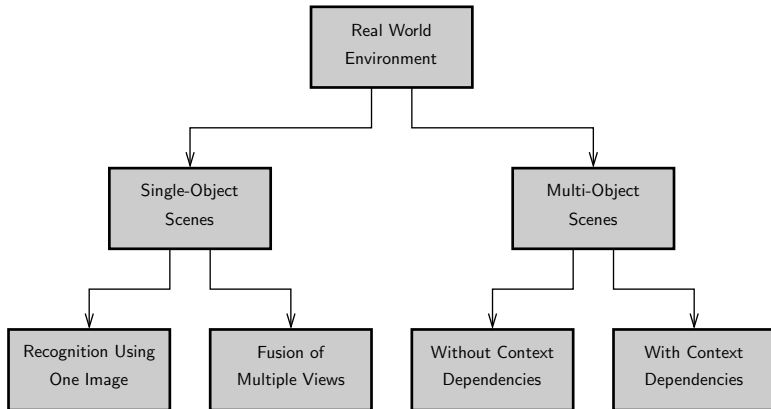
Research  
Overview

Object  
Recognition

Conclusions



# Recognition Phase Completed



Introduction

Research  
Overview

Object  
Recognition

Conclusions

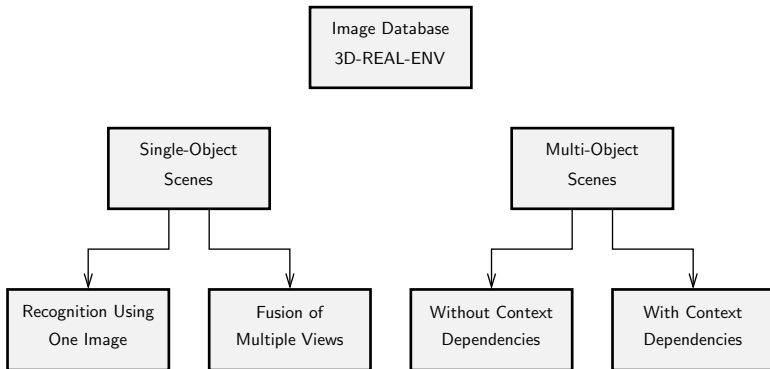
# Experiments and Results

Introduction

Research  
Overview

Object  
Recognition

Conclusions



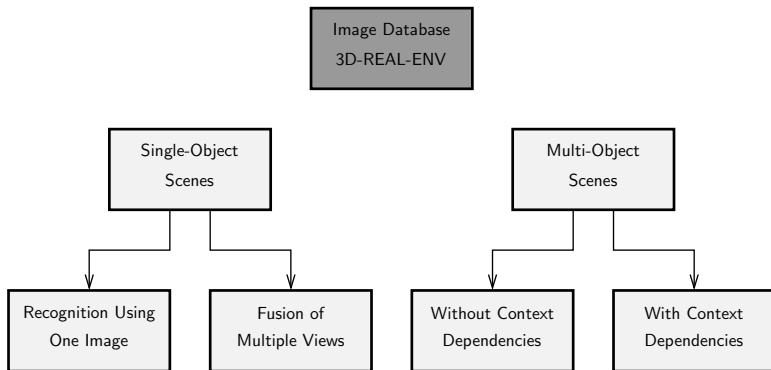
# Image Database 3D-REAL-ENV

Introduction

Research  
Overview

Object  
Recognition

Conclusions



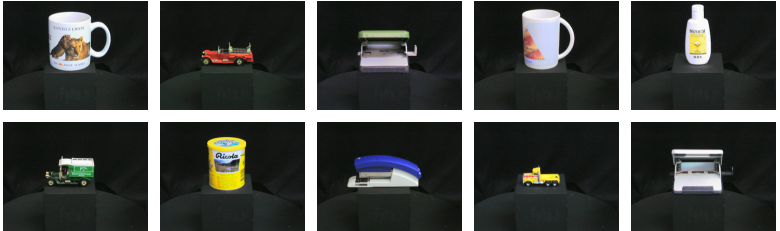
# Training Images

Introduction

Research  
Overview

Object  
Recognition

Conclusions



1680 Training Viewpoints, 33600 Images

$$\phi_{x,\rho} = (0.0^\circ, 4.5^\circ, 9.0^\circ, \dots, 85.5^\circ, 90.0^\circ)$$

$$\phi_{y,\rho} = (0.0^\circ, 4.5^\circ, 9.0^\circ, \dots, 351.0^\circ, 355.5^\circ)$$



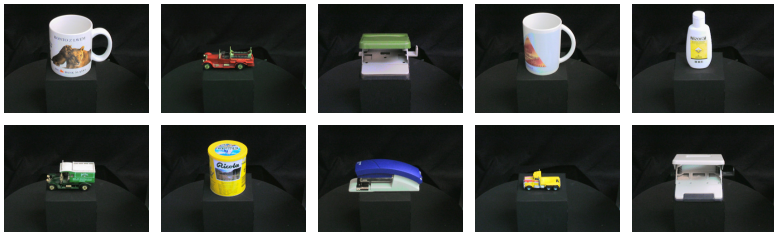
# Test Images HomBack

Introduction

Research  
Overview

Object  
Recognition

Conclusions



288 Test Viewpoints, 2880 Images

$$\phi_{x,\tau} = (0.00^\circ, 11.25^\circ, 22.50^\circ, \dots, 78.75^\circ, 90.00^\circ)$$

$$\phi_{y,\tau} = (0.00^\circ, 11.25^\circ, 22.50^\circ, \dots, 337.50^\circ, 348.25^\circ)$$

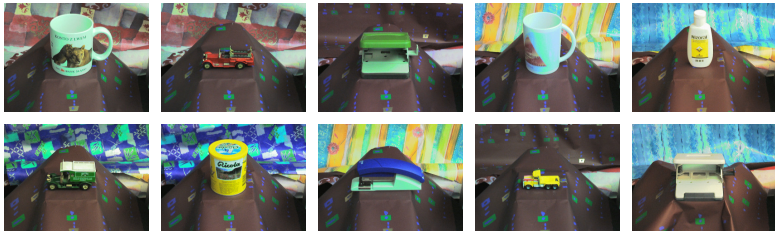
# Test Images LessHetBack

Introduction

Research  
Overview

Object  
Recognition

Conclusions



288 Test Viewpoints, 2880 Images

$$\phi_{x,\tau} = (0.00^\circ, 11.25^\circ, 22.50^\circ, \dots, 78.75^\circ, 90.00^\circ)$$

$$\phi_{y,\tau} = (0.00^\circ, 11.25^\circ, 22.50^\circ, \dots, 337.50^\circ, 348.25^\circ)$$

# Test Images MoreHetBack

Introduction  
Research  
Overview

Object  
Recognition

Conclusions



288 Test Viewpoints, 2880 Images

$$\phi_{x,\tau} = (0.00^\circ, 11.25^\circ, 22.50^\circ, \dots, 78.75^\circ, 90.00^\circ)$$

$$\phi_{y,\tau} = (0.00^\circ, 11.25^\circ, 22.50^\circ, \dots, 337.50^\circ, 348.75^\circ)$$

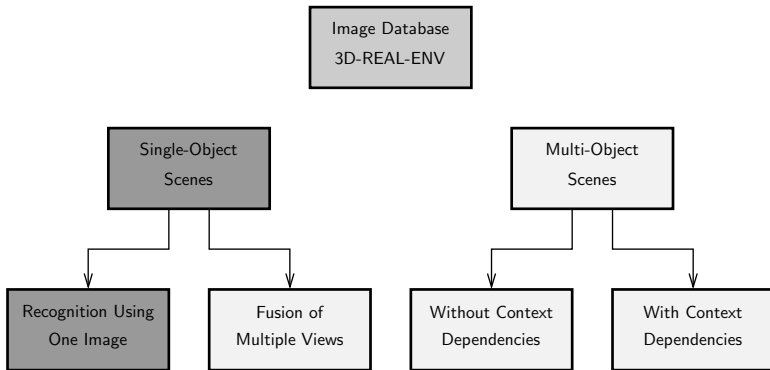
# Single-Object, One Image

Introduction

Research  
Overview

Object  
Recognition

Conclusions



# Classification and Localisation Rates

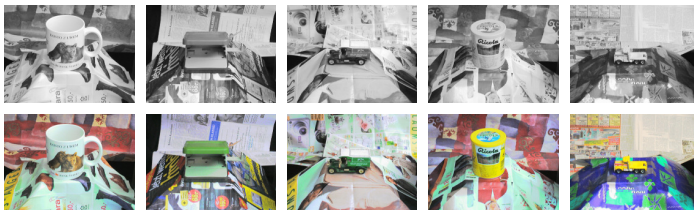
Introduction

Research  
Overview

Object  
Recognition

Conclusions

Distance of Training Views 4.5°	Classification			Localisation		
	Hom. Back.	Less Het. Back.	More Het. Back.	Hom. Back.	Less Het. Back.	More Het. Back.
Gray Level	100%	92.2%	54.1%	99.1%	80.9%	69.0%
Colour	100%	88.0%	82.3%	98.5%	77.8%	73.6%



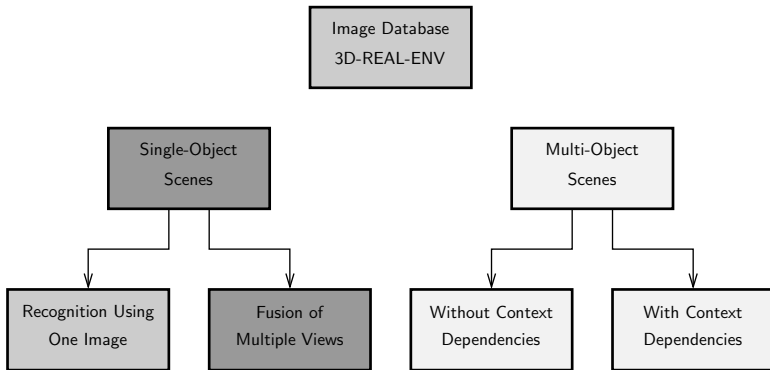
# Single-Object, Multiple Views

Introduction

Research  
Overview

Object  
Recognition

Conclusions



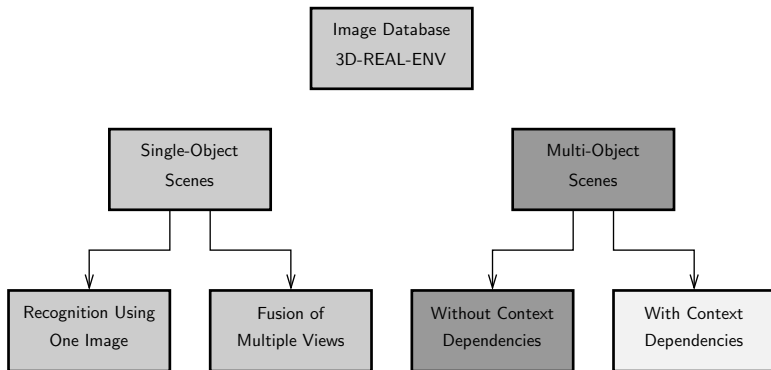
# Multi-Object, Without Context

Introduction

Research  
Overview

Object  
Recognition

Conclusions



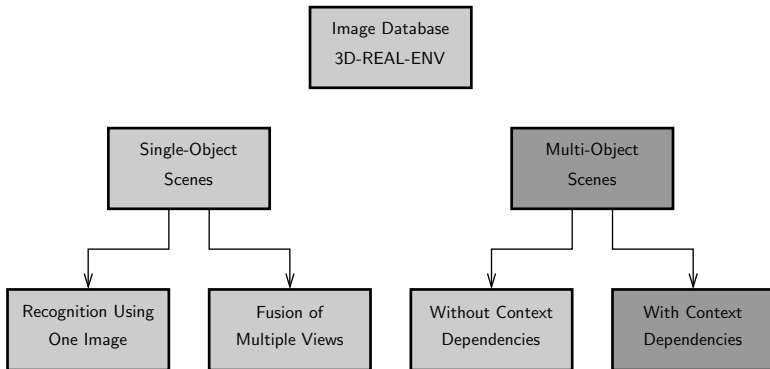
# Multi-Object, With Context

Introduction

Research  
Overview

Object  
Recognition

Conclusions





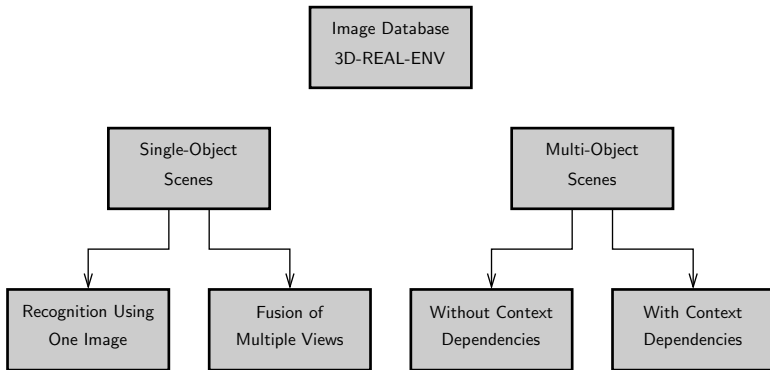
# Evaluation Completed

Introduction

Research  
Overview

Object  
Recognition

Conclusions



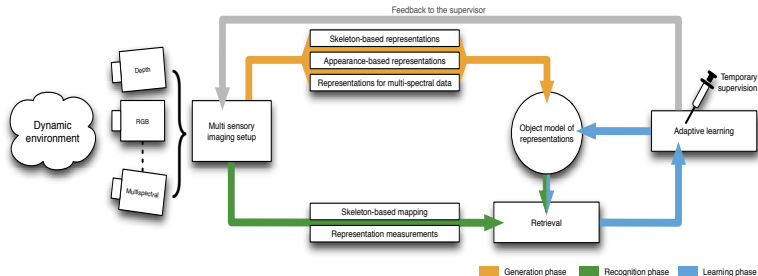
# Adaptive Learning for Object Recognition

Introduction

Research  
Overview

Object  
Recognition

Conclusions



# Overview

Introduction

Research  
Overview

Object  
Recognition

**Conclusions**

1 Introduction

2 Research Overview

3 Object Recognition

4 **Conclusions**

# Adaptivity and Background Knowledge

## Object Recognition

- Start: A System for Appearance-Based Statistical Object Recognition  
Including Colour and Context Modelling
- Vision: Adaptive Learning of Context for Object Recognition

## Multimedia Retrieval

- Start: Multimedia Content Management and Retrieval System
- Vision: Adaptive Learning of User Preferences based on Relevance Feedback

## Image Understanding

- Start: Spatial Reasoning for Image Classification
- Vision: Integration of High-Level Background Knowledge from Ontologies into Low-Level Image Processing

Introduction

Research  
Overview

Object  
Recognition

Conclusions

# Existing Collaborations

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## Object Recognition

- Prof. Kropatsch, Vienna University of Technology
- Prof. Latecki, Temple University of Philadelphia
- Prof. Paulus, University of Koblenz-Landau
- Prof. Pizlo, Purdue University, West Lafayette

## Multimedia Retrieval

- Prof. Izquierdo, Queen Mary University of London
- Prof. Rüger, Open University
- Prof. Uehara, Kobe University

## Image Understanding

- Prof. Haas, Joanneum Research in Graz
- Prof. Staab, University of Koblenz-Landau

# New Research Field - Biometry

Introduction

Research  
Overview

Object  
Recognition

Conclusions

## **Driver Condition Monitoring with Smartphones**

- Assessment of Smartphone Sensors for Driver Condition Monitoring
- Driver Profile Learning from Multimodal Smartphone Sensory Data
- Runtime Automatic Driver Condition Recognition
- New Promising Collaboration with Prof. Krajewski, University of Wuppertal

## **Human Identification using Palm-Vein Images**

- Robust Sensory Setup for Acquisition
- Graph-Based Matching for Similarity Measure