Human Understanding
Machine Understanding

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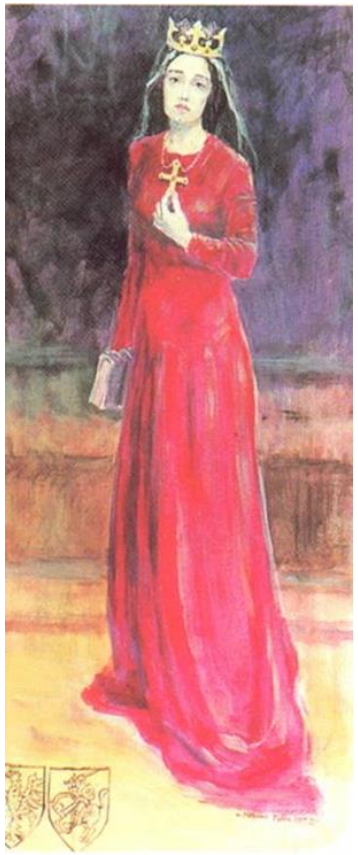
St. Queen Jadwiga's Research Institute of Understanding


HUMAN UNDERSTANDING
MACHINE UNDERSTANDING

St. Queen Jadwiga's Research Institute of Understanding

- The aims of SQJRIU:
  - creating a suitable environment for research concerning all aspects of understanding
  - conducting the original research that investigates different aspects of understanding, and
  - exchanging research results



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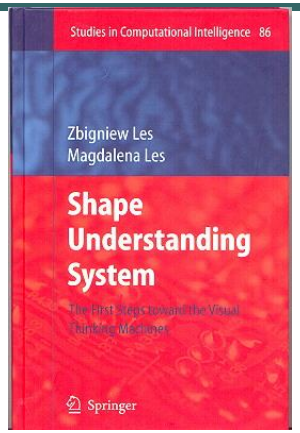
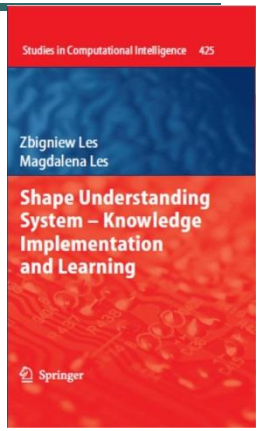
Outline of lecture

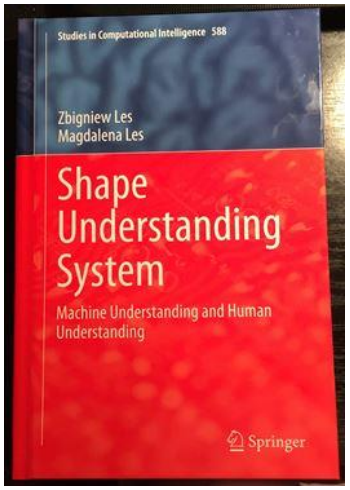
- The presentation of the point of view of selected thinkers on the topic concerning understanding
- A short survey of existing systems that can be regarded as the simple understanding systems
- The presentation of the machine understanding defined in the context of both human understanding and existing systems
- Conclusions

This lecture is based on our books

- *Shape Understanding System: the First Steps toward the Visual Thinking Machines* (Springer 208)
- *Shape Understanding System: Knowledge Implementation and Learning* (Springer 2013)
- *Shape Understanding System: Machine Understanding and Human Understanding* (Springer 2015)
- and on the latest research in area of machine understanding



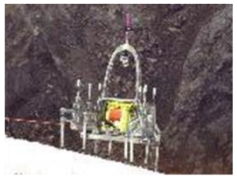




INTRODUCTION
ROBOTS – Machine Understanding

- Machine understanding is aimed to build the most advanced robots
- Robotics – the research area focused on building machine that can do some work (robots)
- The latest generation of robots – (machine understanding) machines' thinking/understanding

Robots



Robot HAL – science fiction

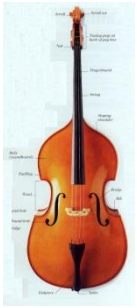
“2001: A Space Odyssey” by S. Kubrick

Understanding

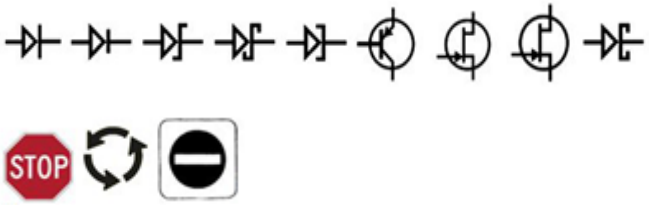
- Understanding is the result of thinking
- It involves processes such as:
  - **learning**
  - **problem solving**
  - **perception**
  - **reasoning**
- It requires abilities such as **intelligence**

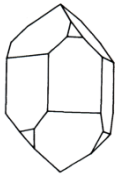
UNDERSTANDING

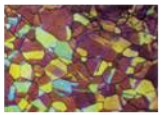
- Understanding refers to the different categories of objects











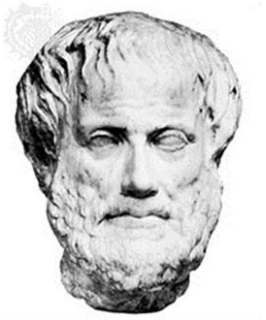



Human Understanding Machine Understanding

- There is no (unique) definition of *human understanding*
  - Comparison of human understanding and machine understanding is based on:
    - the results of philosophical investigations
    - *not* on the results of scientific research
  - Some problems related to human understanding are topics of research in the area of **psychology, linguistics, cognitive science** or **artificial intelligence, however**
    - there are also problems that are not subjected to scientific methodology (empirical research)

Human Understanding
Machine Understanding

- Comparison of ***human understanding*** and ***machine understanding*** is based on



  - **the results of philosophical investigations**

- *Human understanding* was differently defined during the long period of philosophical inquiries

Human Understanding Philosophical Investigations

- **PERCEIVED OBJECT - IDEA - UNDERSTANDING**

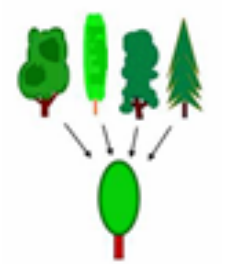
  - **PERCEIVED OBJECT - IDEA -** is a key to understand human understanding (**Plato, Aristotle, Lock, Berkeley** or **Kant):**
    - for **Plato** *understanding* is grasping of **ideas**
      - **an Idea refers to particular things** in the empirical world that are **imperfect reflections** of the **Idea**
    - for **Aristotle** *understanding* is connected with perception were ideas (concepts) are extracted from perceived data based on the **abstraction and generalization**
    - for **Locke** *understanding* is grasping the relations between **ideas**

Human Understanding Philosophical Investigations

- **PERCEIVED OBJECT - IDEA - UNDERSTANDING**
  - for **Kant** *understanding*
    - begins by means of **objects** which affect our senses
    - produce **representations**
    - rouse our powers of *understanding* into activity:
      - **to compare**,
      - **to connect**, or
      - **to separate**, and
      - **to convert** the raw material of our sensuous impressions into the knowledge of objects **(Ideas)**

Human Understanding Philosophical Investigations

- All **ideas** formed in the **mind** are the result of **sensory impressions**
  - the **basic ideas** are the result of the faculty of mind called **intuition**
  - the **basic ideas** are formed based on the impression that comes from the **abstraction** of sensory material
  - The **idea** (concept) is extracted from the sensory images and used in thinking/understanding process



Human Understanding Philosophical Investigations

- **IDEA (form, concept, universal) -** was differently understood by philosophers
- **Ideas** are:
  - objects of mental life
  - *objects of sensory perception*
  - *forms and phantasms*
  - sensory images,
  - sensory states,
  - abstract thoughts, or
  - contents of such thoughts

$Q^1[L_R^4](L^3)$

Human Understanding Philosophical Investigations

- **PERCEIVED OBJECT – MEANING - UNDERSTANDING**
- **Meaning of the object – a key to understanding (Husserl)**
  - **Husserl,** when still absorbed with an object, pointed to **the meaning of the object** as its **essentia**l cognitive ingredient
  - **Husserl** introduced distinction between ***natural*** and **phenomenological** modes of **understanding**
  - ***natural* understanding** is based on the **perception** that constitutes the known reality
  - **phenomenological understanding** is based on **phenomenological reduction**
  - **phenomenological reduction** is based on consciousness of any given object that **discern its meaning** as an **intentional object**
  - **intentional object** does not simply strike the senses to be interpreted by mental reason but it has already been **selected and grasped**

Human Understanding Philosophical Investigations

- **LANGUAGE – KNOWLEDGE - UNDERSTANDING**
- **Language –** a key to understanding (Frege, Wittgenstein and Russell)
  - **Frege, Wittgenstein and Russell** - formal language and mathematical modeling important components of *understanding*
  - **Wittgenstein** developed a comprehensive **system of logical atomism** as a formal language of science
  - **for Russell** understanding is connected with searching for an **ideal language** for **representing the scientific facts**
  - **For analytic philosophy (logical positivism)** ***understanding*** is based on logical clarification of thoughts by analysis of the logical form of philosophical propositions

    Logical positivism used formal logical methods to develop an empiricist account of knowledge

Human Understanding Philosophical Investigations

- **LANGUAGE – KNOWLEDGE – UNDERSTANDING**
- **Logical Positivists:**
  - adopted the verification principle according to which every **meaningful statement** is either **analytic** or **can be verified by experiment**
  - rejected many traditional problems of philosophy- **metaphysics or ontology** as **meaningless**
  - claimed that statements **of ethics, aesthetics and theology** are pseudo-statements, neither true nor false but simply **meaningless**
- **For Popper** *understanding* is connected with the **progress of scientific knowledge**
- **For Kuhn** understanding refers to **scientific knowledge that is a series of paradigms**

Human Understanding Philosophical Investigations

- **TEXT – INTERPRETATION – UNDERSTANDING**
  - **Interpretation of the text –** a key to understanding

Hermeneutics (**Schleiermacher, Gadamer, Heidegger**)

  - Language understanding is embedded in understanding process that involves understanding of all aspects of human activities
    - **Hermeneutics** is the **art of understanding** the written discourse of another person correctly
    - **Hermeneutics** was initially applied to the interpretation of scripture and emerged as a **theory of human understanding** through the work of **Schleiermacher** and **Dilthey**

Human Understanding Philosophical Investigations

- **TEXT – INTERPRETATION – UNDERSTANDING**
  - **Schleiermacher -** understanding of the text is **to find the author's intentions**
  - **Gadamer -** the **context** **o**f **interpretation** determines a text's meaning and reveals something about the social context in which texts were formed
  - **Gadamer -** the **nature of human understanding** can be discovered by means of **philosophical hermeneutics**
  - **Heidegger's** philosophical hermeneutics shifted the focus from interpretation to existential understanding
  - **Modern hermeneutics** includes both verbal and nonverbal communication and semiotics

Human Understanding Philosophical Investigations

- **BRAIN – FUNCTION - UNDERSTANDING**
  - **Brain –** a key to understanding (Hobbes, Spinoza)
  - **Hobbes and Spinoza** believed that humans are **deterministic machines** with **understanding explainable by scientific methods**
  - Modern philosophers **(logical behaviorism or functionalism**) regarded the problem of understanding as the problem **of mind functions**
  - **Functionalism** identifies **mental states** with **brain states** and explains understanding in terms of **cognitive theory**
  - **Cognitive theory** attempts to explain human understanding by comparing the mind to a **sophisticated computer system**

Machine Understanding

- **Machine Understanding**
- is the term introduced by authors to denote *understanding by a machine*
- is **the first attempt** to **establish the scientific method to investigate the complexity of understanding of problems**
- is referring to **the new area of research** the aim of which is to investigate the possibility of building a machine with the ability to understand

Machine Understanding

- **Machine Understanding**
  - is based on the results of **investigations of logical positivists**
  - makes it possible to study the selected aspects of understanding
  - provides the suitable model of understanding that can be approached using scientific methods
  - is defined in the context of both human understanding and existing systems that can be regarded as the simplest understanding systems
  - is based on the development of the shape understanding system (SUS)

Machine Understanding

- **Machine understanding**
  - is based on the assumption that the results of understanding by the machine (SUS) can be evaluated according to the rules applied for evaluation of human understanding
  - **can only to some extent approximate human understanding**
  - requires very good programming skills C++ and knowledge of algorithms from the deferent domains:
    - numerical methods, computational geometry, graph, image processing, signal processing and others

Machine Understanding
Simple understanding systems

- **Machine understanding** is defined in the context of both **human understanding** and existing systems that can be regarded as the **simplest understanding systems**
  - **Simple understanding systems** are built in the areas of:
    - **expert systems,**
    - **image understanding,**
    - **language understanding, or**
    - **robotics**

Machine Understanding

- **Machine understanding** refers to different ontological categories of objects:
  - **the visual object:**
    - the real world object
    - the sign
  - **the sensory object**
  - **the text object**

Machine Understanding
Shape Understanding System (SUS)

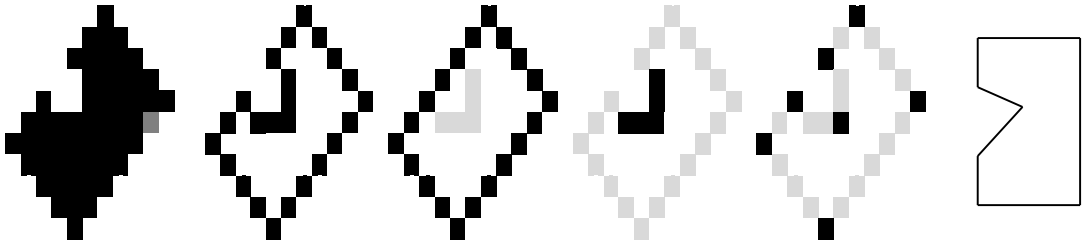
- **SUS**
  - is the first system that is designed to have an ability to **think and understand**
  - is the first system that is designed to cope with difficulties of **visual knowledge representation**
  - is the implementation of **shape understanding method**
  - makes it possible to study the different processes connected with understanding by providing the suitable model of understanding
  - has ability to learn both knowledge and skills

MACHINE UNDERSTANDING
Basic concepts – Reasoning

- **The reasoning process is**
  - part of the **visual reasoning process**
  - performed passing the consecutive stages of reasoning $\varsigma_0 \rightarrow \varsigma_1 \cdots \rightarrow \varsigma_N$
- During each stage the sequences of **image transformations** are applied in order to find a set of descriptors

$$\Theta_{\mathrm{X}}^{\lambda} : \mathrm{X} -> \mathrm{X}$$

$$L_{\alpha_1} \bullet L_{\alpha_2} \bullet \ldots \bullet L_{\alpha_M} : \mathrm{X}^{\alpha_0} \rightarrow \mathrm{X}^{\alpha_M}$$

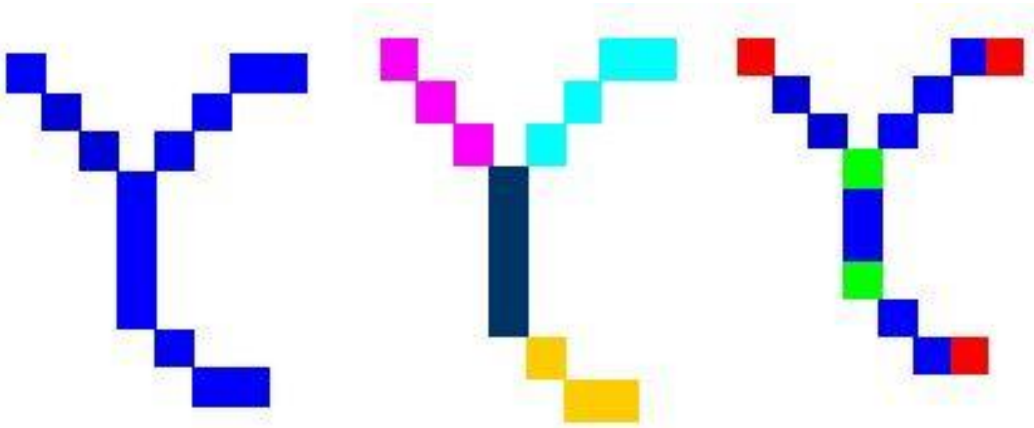


MACHINE UNDERSTANDING

Basic concepts – Image Transformations

- Example
- **The image transformation point-point**
  - computation of a set of critical points of the skeleton

$$\Theta^1 : X^S -> X^B \qquad \Theta^2 : X^B -> X^K$$

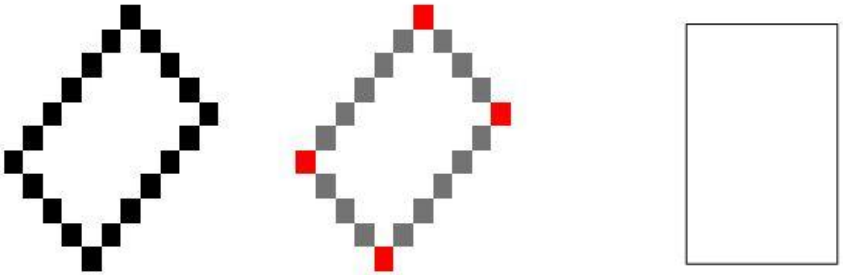


MACHINE UNDERSTANDING
Reasoning – an example

- Example

A reasoning process

- A stage of reasoning $\zeta_i \equiv L^m$
- An image transformation $\lambda_\psi : \coprod^B \to \coprod^\psi$
- A descriptor transformation $\iota_\mp = \aleph_\mp(\coprod^\mp) = 4$
- An assignment to the class $[\iota_\Phi = t_\Phi] \Rightarrow s \triangleright L^4$



MACHINE UNDERSTANDING
Reasoning – an example

- **Example - more complex reasoning process**

The stage of reasoning $\zeta_0 \equiv Q$:

- the processing transformation:

$\Delta_B : X^F \to X^B \qquad \Delta_{\aleph} : X^B \to X^{\aleph} \quad \partial_H : X^{\aleph} \to I^H \quad \partial_{\aleph} : I^H \to I^{\aleph},$

- the descriptor transformation: $\iota_C = \aleph_C(I^{\aleph}) = \frac{|I^{\aleph}|}{|X^F|} = \frac{8}{59} = 0.14,$

- the rule: $[\iota_C > T_C] \tilde{\Rightarrow} s > Q \quad [0.14 > T_{0.05}] \tilde{\Rightarrow} s > Q.$

The stage of reasoning $\zeta_1 \equiv Q^m$:

- the processing transformation:

$\Delta_{\Psi} : X^B \to X^{\Psi} \qquad \Delta_{\Phi} : X^B \to X^{\Phi}$

- the descriptor transformation: $\iota_{\Phi} = \aleph_{\Phi}(X^{\Phi}) = 1$

- the rule: $[m = \iota_{\Phi}] \Rightarrow s > Q^m \quad [m = 1] \Rightarrow s > Q^1$

The stage of reasoning $\zeta_2 \equiv Q^m[L^n]$:

- the descriptor transformation: $\iota_{\aleph} = \aleph_{\aleph}(X^{\aleph}) = 4$

- the rule: $[n = \iota_{\aleph}] \Rightarrow s > Q^m[L^n] \qquad [n = 4] \Rightarrow s > Q^1[L^4].$

The stage of reasoning $\zeta_3 \equiv Q^m[L^n](n \bullet L^h)$:

the processing transformations:

$\Delta_{\Sigma} : X^B \to X^{\Sigma} \quad \Delta_{\Sigma} : X^B -> X^{\Sigma} \qquad \Delta_O : X^{\Sigma} -> X^O$

the descriptor transformation: $\iota_{\Psi} = \aleph_{\Psi}(X^{\Psi}) = 3$

the rule: $[h = \iota_{\Psi}] \Rightarrow s > Q^m[L^n](n \bullet L^h)$

Machine Understanding Learning

- Modern knowledge-based systems acquire knowledge during the learning process
- In machine understanding a system **acquires knowledge and skills** in the process called **knowledge implementation**
- **Knowledge implementation** is based on the assumption that a system to be able to understand needs to learn knowledge that is fully understood

Machine Understanding Learning

- **Learning of visual knowledge of the selected category is to learn of visual concepts of this category**

Visual knowledge of the category v_i is learned as a visual concept represented as a set of symbolic names $\varphi_c = \{\eta_1, \eta_2, ..., \eta_n\}$.

It is assumed that a set $v_i(o)$ represents all visual aspects of the category v_i.

During learning of the knowledge of visual objects, at first, the representative sample of objects from the category $\mathbf{u} \in \mathbf{v}$ is selected, then for each object the symbolic name η_i is obtained and finally the visual concept of this category as a set of symbolic names $\varphi_c^j(\mathbf{v}) = \{\eta_1, \eta_2, ..., \eta_n\}$ is learned.

Machine Understanding Learning

- **Learning of a visual concept**
- **A visual concept** is obtained during learning and is given as a set of symbolic names

$$\varphi^k = \{\eta_1^k, \eta_2^k, ..., \eta_n^k\}$$

  - An example – learning of the visual concept of members of the arrow category

$$\varphi_{Ar} = \{Q_{L^5}^2(2L^3), C^2(L^4L^3), \Xi\ (\Theta^2L^3), \Theta^3\}$$

Machine Understanding Learning

- **Learning of the visual concept is performed by applying the learning algorithm**

For selected category $\mathbf{v}$ the visual concept is obtained in the following stages of the learning algorithm:

For all $u_i \in \mathbf{u}$, $i = 1,...,n$, $\mathbf{u} \in \mathbf{v}$ do:

1. Transform a phantom u_i into its digital representation using a perceptual transformation

$$\Im(u_i) = o_i - \mathrm{X}^i .$$

For each X^k perform reasoning:

2. Assume $\zeta_j \equiv \zeta_0 \equiv \Omega[\zeta_0]$, $\mathrm{X}_i^k \equiv \mathrm{X}_i^0$.

At the j-th stage $\zeta_j \equiv \Omega[\zeta_j]$ assume that an examined object o_i is assigned to the class $\Omega[\zeta_j]$.

Apply the processing transformation: $\Delta_k : \mathrm{X}_i^k \to \mathrm{X}_i^{k+1}$.

Apply the descriptor transformation: $\iota_h = \aleph_h(\mathrm{X}_i^{k+1})$.

Apply the rule: $[\iota_h > T_h] \Rightarrow o_i > \Omega[\zeta_{j+1}]$.

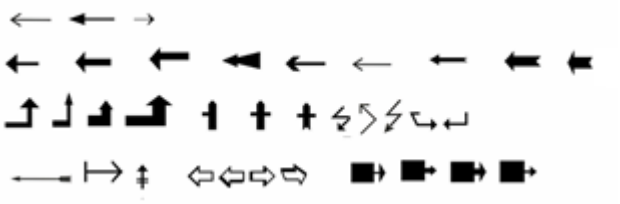
If $\zeta_j \equiv \Omega[\zeta_j]$ is the final stage, assume $\eta_i \equiv \Omega[\zeta_j]$.

If i<n, i=i+1 goto 1 else END.
else
j=j+1, goto 2.

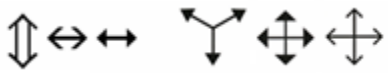
As a result of applying this algorithm the visual concept $\varphi(v_i) = \{\eta_1, \eta_2, ..., \eta_n\}$ is obtained.

Machine Understanding Learning

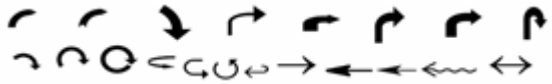
- **Example**
- objects from the different specific arrows categories used for learning of the visual concept of the arrow category
- **The category of arrows with straight lines - one head**



- **The category of arrows with straight lines - more than one head**



- **The category of arrows with curved lines**



Machine Understanding
VISUA UNDERSTANDING - VISUAL LEARNING

- **Visual Understanding** requires knowledge that is acquired during **visual learning**
- **Visual learning** involves:
  - generalization
  - specialization
  - schematization
  - visual abstraction
  - imaginary transformation
  - conceptual magnification
  - perceptual magnification

Machine Understanding
Understanding of Visual Objects

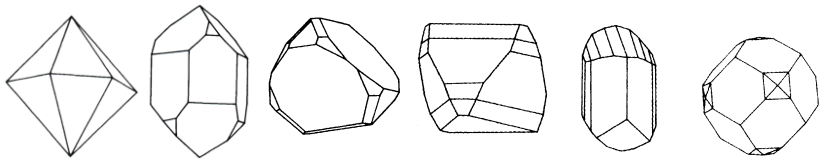
- Understanding of the perceived object is to extract this object from the background

  - The different backgrounds require applying the different segmentation methods to extract the object from the background

Machine Understanding Understanding of Visual Objects

- **Understanding of real world objects** refers to the different visual representations
- Understanding requires to learn visual knowledge of all visual representations of the object

- Visual understanding refers to the 2D representations of the object



Machine Understanding
UNDERSTANDING OF TEXT

- STA definition is given in different forms such as the linguistic description or in the form of symbolic expressions (formal definition)
- The definition given as the formal definition needs to be transformed into the mathematical definition and to the linguistic definition
- **Example**
- the definition $X \subset Y \equiv \prod_{x}(x \in X \rightarrow x \in Y)$
- *can be translated into*
- *the set X is included in the set Y (set X is a part of the set Y), or*
- *(the set X is a subset of the set Y) if and only if every element of the set X is an element of the set Y*”

Machine Understanding
UNDERSTANDING OF TEXT

- Deep understanding refers to the specific basic forms and is given by the learned explanatory script
- The specific basic forms revel the specific meaning of all categories used in the given definition (words or phrases)
- The specific meaning can refer to the related field of mathematics or other areas of science
- **Example**

set is collection of objects of any kind (**set can consist of any category of object**),
intuitively set is any well defined collection of objects (**"intuitively" means that definition of set is based on intuition or axioms**), (**'any well defined' means that all objects in the set are objects of well known categories and learned categories**),
any collection of objects will be called set ("**will be called" can be exchanged by is**),
any collection of objects will be called set or class (**'class' is synonym for set**).

Gift to the Ian Potter Gallery at the University of Melbourne