CSG6120-01
인지과학특강 I
(Theory of Mind for Robots)

Spring Semester, 2011
Teaching Staff

Lecturer
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Hours: 화요일 오후 2~4시, 오후 5시~6시

Place: A542

Office Hours: 화요일 4시~5시
Robot and Cognitive Science

Cognitive Robotics
Robot Psychology
Experimental Robotics
Developmental Robotics
Bio-Inspired Robotics

Cognitive Science
Robotics
Cross Fertilization

- Biological Inspiration
- Computational Model

Cognitive Science

Robotics

- Engineering Inspiration
- Virtual Humans and Animals
- Reverse Engineering Cognitive Functions
Theory of Mind

Theory of mind is the ability to attribute mental states—beliefs, intents, desires, pretending, knowledge, etc.—to oneself and others and to understand that others have beliefs, desires and intentions that are different from one's own.
Course Goals

- Theory of Mind에 대한 이해 및 최신 연구 동향 파악
- 인지과학의 연구 도구로 Robotics 기술 이해
- Robot을 위한 Theory of Mind 관련 연구 이해 및 연구 주제 수행
Course Materials

- Reading in Theory of Mind for Robots
  - Theoretical Foundations for Theory of Mind
    - Theory, Neuroscience, Animal Study ....
  - Applications for Simulated Robots
    - Virtual Character, Robot Simulator
  - Applications for Real-Robots
    - Real Robots (E-Pucks, Humanoids, …)
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Resources

- E-Pucks
- Optical Tracking Devices (OptiTrack)
- IR Light Source (SiMa Night Vision)
Evaluation Criteria

- Term Project (written report and an oral presentation) : 70%
- Class Presentation : 20%
- Class Participation : 10%

Term Project (Oral presentation is required) :
- Theoretical Issue (Analysis, Experiment, Simulation) : Originality
- Interesting Programming (Game, Demo, etc) : Performance
- Survey : Completeness
Basics in Theory of Mind
Mind Reading
Non-Human Theory of Mind
They Can Do?
This is Sally.

This is Ann.

Sally has a ball. She puts it into her basket.
Sally goes out for a walk.
Ann takes the ball out of the basket.

Ann then puts the ball in the box.

Now Sally comes back.
She wants to play with the ball.

Where will Sally look for the ball?
Theory of Mind Cartoons
Non Theory of Mind Cartoons
Recursive Nature of ToM

Jack: Mental state
Jill: Mindreading
Jack: Embedded mindreading (First recursion)
Robotics Approach
(Self Modeling)
Self-model synthesis

Robot generates several self-models that match sensor data collected while performing previous actions. It does not know which model is correct.

The cycle continues at step b to further refine models, or at step d to create new behaviors.

Exploratory action synthesis

Robot generates several possible actions that disambiguate competing self-models.

Target behavior synthesis

Robot physically performs an action. Initially, this action is random; subsequently, it is the best action generated in step c.

The best locomotion sequence is then executed by the physical robot.

After several cycles of a-c, the currently best model is used to generate a locomotion sequence through optimization.
Robotics Approach
(Theory of Mind)
False Belief in Second Life

In which a robotic security guard passes the false belief task, by correctly predicting where an agent would look for a hidden firearm.
2008.02.07

Selmer Bringsjord
Andrew Shilliday
Joshua Taylor
RASCALS: Rensselaer Advanced Synthetic Character Architecture for “Living” Systems

- Military Combat
- Military Strategy
- Intelligence Analysis
- ITS
- Games / Interactive Entertainment

DISPOSITIONS
"NARRATIVE NATURE"
EDUCATION

DYNAMIC BELIEFS

First-Order Logic

PARSER

PLANNER

Q&I Modules (Reactive Processing)

- NAVIGATION
- BASIC ACTIONS
- ROUTINIZED ACTION
- SHALLOW NLP

Percepts (depends on which testbed)
- ITS: proof snapshots and submitted proofs
- CHOGIC: chess/checkers configurations
- UNREAL: Torrey, targets in field of vision
- INT Gaming: information about suspects, etc.

Actions

-MANUAL ACTIONS

Humans

First-Order Logic

MML-Based Heterogeneous Reasoning
- Multi-Agent Reasoning
- Narratological Reasoning
- MML-based Provers

Practical Reasoning

NLG
Theory of Mind for Humanoids

MIT, 2000

Gazing
Face Detection
Infer Simple Intention

Brian Scassellati
Mario et al. (2007)

Approaching a ball
Approaching an yellow box
Approaching another player
Pushing a ball to an yellow box
Pushing a ball to another player
Robotics Approach
(Neural-basis)
Theory of Mind in Robotic Society

A: I Know “You”!
B: I Know “You Know Me”!
A: I Know “You Know I Know You”!
B: …
Scenario

① Infer Other’s Brain

② Exploitation
From Virtual To Real

① PhysX
② EnKi
③ E-Puck
Controller (Neural Network)

Left Light Sensor Value

Right Light Sensor Value

Steering Angle

Velocity
Candidate models

\[
\begin{align*}
\frac{dx}{dt} &= -2y^2 + \log x \\
\frac{dy}{dt} &= -x + \frac{y}{6} \\
\frac{dz}{dt} &= -3\frac{y + 1}{y - 1} \\
\frac{dx}{dt} &= -\frac{x^2}{x^2 + 1}
\end{align*}
\]

Candidate tests

\[
\begin{align*}
\frac{dx}{dt} &= -\sqrt{y} + \frac{x}{5} \\
\frac{dy}{dt} &= -4\sin y \\
\frac{dx}{dt} &= y^2 + \log x \\
\frac{dy}{dt} &= -x + \frac{y}{4x}
\end{align*}
\]

\(\text{Candidate initial conditions}\)

**Inference Process**

**a** The inference process physically performs an experiment by setting initial conditions, perturbing the hidden system and recording time series of its behavior. Initially, this experiment is random; subsequently, it is the best test generated in step c.

**b** The inference process generates several different candidate symbolic models that match sensor data collected while performing previous tests. It does not know which model is correct.

**c** The inference process generates several possible new candidate tests that disambiguate competing models (make them disagree in their predictions).
[Original]    [Reconstructed]

Left Light Sensor Value

Right Light Sensor Value

Sensor Value

Left Light Sensor Value

Right Light Sensor Value

speed
Real Robot Scenarios
Possible Projects
Overview

Robot

Behavior (Trajectories)

ToM 알고리즘

Estimated One

인공 신경망 (Robot’s Mind)
Possible Project Lists I (Survey)

- Theory of Mind를 설명하는 이론들에 대한 조사
- Brain-Imaging을 통해 밝혀진 Theory of Mind 관련 사실들 조사
- 인간이 아닌 다른 동물들의 Theory of Mind에 대한 조사
- Theory of Mind를 테스트 하는 방법에 대한 조사
possible project II (로봇 시뮬레이션)  

- ToM 알고리즘의 종료 조건 테스트 (다양한 조건들 중에 어떤 것이 최적인 지 실험적으로 테스트)
- ToM 알고리즘에서 상대방 로봇의 행동 데이터들을 어떻게 활용하는 것이 최적인지 테스트 (가장 최근에 얻어낸 데이터만 이용/과거 데이터도 모두 이용/가중치를 부여하여 이용)
- ToM 알고리즘에서 상대방 로봇의 행동 데이터를 어떻게 얻는 것이 최적인지 테스트 (random하게 얻어온다/능동적으로 필요한 데이터를 얻어온다)
- ToM 알고리즘에서 두 Trajectory가 닮았다는 것을 어떻게 측정하는 것이 좋은가? (Euclidean Distance, Derivatives …)
- ToM 알고리즘에서 상대방 로봇의 행동 데이터를 사용할 때 그 trajectory의 각 segment가 서로 다른 중요도를 가진다고 보고, 그 중요도를 최적화 한다.
Possible Project III (실제 로봇)

- Reality Gap (Simulator와 실제 로봇) 최소화
  - OptiTrack 이용
  - Sensor Models ( 서로 다른 정밀도 지님)
  - Motor Adjustment Parameters
  - Reality Gap이 얼마나 줄어드는지 평가

- Immature Neural Controller 진화
  - 단순히 직진으로 빛을 따라가는 최적화한 제어기 보다는
  - 회전하거나 커브를 그리는 형태의 제어기를 선호
  - Long-Term Exposure Shot으로 로봇 행동 촬영하기