Realtime Object Recognition Method Inspired by Multimodal Information Processing in the Brain for Distributed Digital Twin Systems

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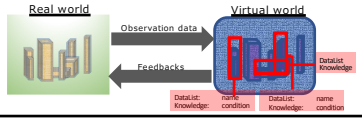
Background — Growing expectations of the Digital Twin

❖Digital Twins
- Represent virtually every aspect of our real world
- Feed back simulated results in digital world to the real world
- Have various applications: warehouse management, safety management, and autopilot

❖Research challenges
- Robust sensing data processing
- Accurate identification of objects and self-location information of sensor devices
- Real-time and wide-area object recognition



Purpose — Realizing the Edge-Cloud Digital Twin

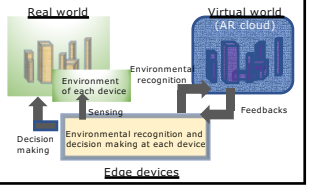
Overall purpose

❖Realizing the edge-cloud digital twin concept using the AR cloud
- Build a localized virtual world by recognizing the environment with sensing devices
- Integrate each device's information on the AR cloud to create a huge virtual world

In this paper

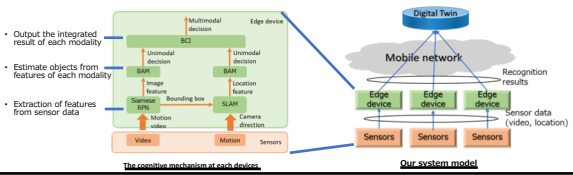
❖Problem: real-time update of virtual world from observed information
- Limitation of processing capability on the cloud
- Latency between devices and the cloud

❖Approach
- Learning from the superior cognitive mechanisms of the human brain to realize the edge-cloud digital twin
- we focus on the multimodal information processing mechanism of the brain



The constructure digital twin learned from human brain

❖Constructing a **probabilistic virtual world** with **the cognitive mechanisms of the brain**
- The cognitive mechanisms of the brain are hierarchically structured
- Define edge devices as cognitive mechanisms that have such functions
- Summarize cognitive results from multiple them to cloud



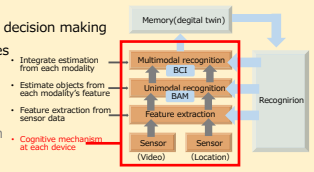
Brain-inspired object recognition methods

Purpose in this paper: Realize quickly and robust object estimation that can cope with real-world environmental changes

Approach

❖Propose an object estimation method inspired by the brain's cognitive mechanism
- Multimodal processing using uncertain information obtained from eyes, ears, and the semicircular canal
- Hierarchical, lightweight and robust decision making

❖Models of the brain's cognitive processes
- Unimodal Processing by "Yuragi Learning" of Brain and Organism **B**ayesian **A**ttractor **M**odel (BAM)
- Multimodal processing based on causal inference by brain perception **B**ayesian **C**ausal **I**nference (BCI)

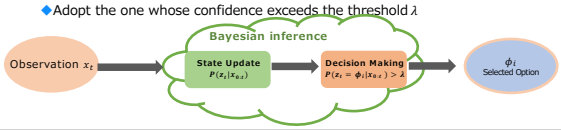


Bayesian Attractor Model (BAM)

❖Mathematical model of the brain's behavior in making decisions based on observations
- Estimate which of the pre-stored options matches the observation target
- Determine which of the previously learned options is closest

❖**State Update:** Internal decision state z_t is updated by receiving external observations x_t
→by Bayesian inference, z_t is a probability distribution $P(z_t)$ that reflects the uncertainty of the brain state.

❖**Decision Making** : One of the pre-learned options (attractors) is adopted
- ◆Prepare as many stable points that are named attractors
- ◆Derive a probability density (hereafter called the confidence level) where zt = φi
- ◆Adopt the one whose confidence exceeds the threshold λ



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Extending the BAM with BCI

❖BCI is a mathematical model of human cognition based on multimodal perceptual stimuli

1. Uni-modal object estimation: Two input stimuli (features of an object) x_L, x_V calculated from 3D location modality and visual modality are input to the BAM
   - The BAM outputs cognitive results S_L and S_V for each modality
2. Multimodal object estimation: Outputs of the BAM is integrated by the BCI
   - Probability that the two stimuli are generated from the same object (or not) is calculated (Causal Inference)
   - Cognitive results are calculated according to the probability (Model Average)

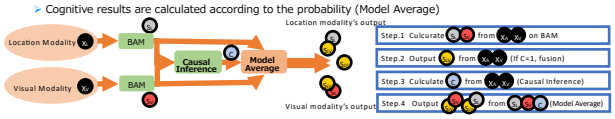

Figure. Extending the BAM with BCI

[1] K. P. Kording, U. Beierholm, W. J. Ma, S. Quartz, J. B. Tenenbaum, and L. Shams, "Causal inference in multisen- sory perception," PLoS one, vol. 2, no. 9, p. e943, 2007.

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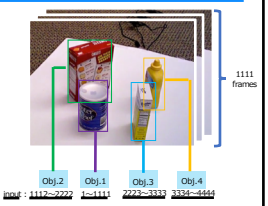
Simulation evaluation

❖Feature extraction in visual and location modalities from video data[2]
- 4 objects in 1111 video frames
- Features are extracted from each bounding box of an object in a frame
- The BAM learns and stores features of each object in the first frame
- The BAM outputs which object is observed with confidence

❖Compare the estimation accuracy between unimodal and multimodal object estimation



[2] Video data of public dataset(Yale-CMU-Berkeley (YCB) Object and Model set)

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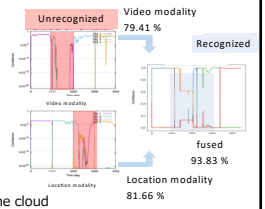
Conclusion

Results

❖I Proposed a method for object estimation based on multimodal uncertain observed information
- **Lightweight** enough to perform estimation on per-device, and **robust** by using multimodality
- Limitation: My proposed method is for a single object only



Future tasks

❖Propose a multi-object estimation method

❖Fusion of estimation results from multi-devices on the cloud

❖Feedback from the cloud to the device and its utilization

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Further Future Challenges

① Detailed system design for single device
- Recognize multiple objects simultaneously

② Construction of an upper layer to store object recognition results from a device

③ Design a system to integrate the recognition results from multi-device

④ Build a method of cooperation between layers