BOOST NAIS

FY2026
"Advanced AI Talent Development to Lead the Next-Generation Intelligent Society" (BOOST NAIS)
[Application for the Spring of 2026]

Graduate School / Department	**The Interfaculty Initiative in Information Studies (III)** **The Emerging Design and Informatics Course**
Name of Applicant	**Earnest Kota (航太) Carr**

＊ Note that you will be disqualified with any lack or mistake of designated documents and other items.
＊ You may be asked to have an interview including online interviews.

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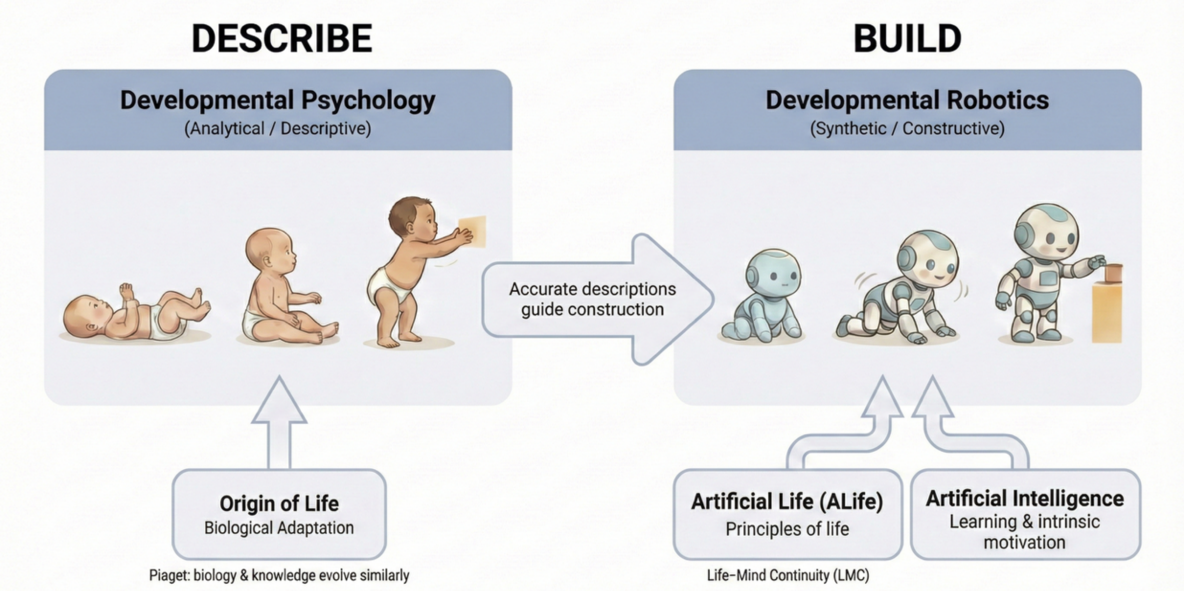
1. Research proposal and its relationship to next-generation AI fields
(**Max. 1 A4 page**. Font size must be 10 pt or larger. You may use charts and tables. Do not alter the format or add pages.)

Bridging Developmental Psychology and Developmental Robotics through Play. Because rewards are fixed in advance, today's AI tends to overfit, take shortcuts ("reward hacking"), and struggle when conditions change. In other words, today's AI can optimize a target, but it does not truly develop. Development means learning to solve new problems without losing old skills. True development requires autonomy: the ability to change goals and reapply knowledge in a changing world. If we want AI that grows alongside humans—staying useful, engaging, and safe—we must build robots based on intrinsic motivation and developmental principles, not just task-by-task optimization.



Two fields hold key pieces of this puzzle, but they are still too separate. Developmental psychology describes how infants explore, grow through cognitive stages, and learn social skills. Developmental robotics builds embodied agents that implement candidate learning mechanisms, evaluates whether these mechanisms can reproduce key developmental patterns and be useful to human society. When combined properly they can turn development from a description into a design principle. My research connects these fields through play. Psychology has long treated play as central to development (e.g., Piaget; Trevarthen). Robotics has studied playfulness and intrinsic motivation—curiosity, novelty/surprise, and control—as drivers of open-ended learning. What is missing is a shared, implementable intrinsic motivation that is precise enough to engineer into developmental robots.

In this research, play is not a metaphor. I treat play as a learning loop with two concrete complementary capacities. **First is dynamic bidirectional engagement:** in rough-and-tumble play, animals keep the interaction or game alive by balancing and oscillating between influence and receptivity (control vs sensitivity)—shaping the exchange while also letting it reshape them, if this balance is not maintained the game ends. In learning terms, play stays in a regime where the bi-directional balance corresponds to **Empowerment–Plasticity** (Abel et al., 2025) and can be tracked with internal signals. **Second is symbolic abstraction (reflective) play:** in pretend play, a child treats a stick as a sword, using abstractions, meanings and roles rather than only objects. In learning terms, this is structure learning: extracting reusable building blocks (like shape or color) from experience that can be recombined in new situations (e.g., Piaget-inspired representation learning; Ohmura et al.).

Together, these two capacities form a **developmental engine.** Bidirectional engagement regulates challenge, pushing the agent to explore safely near its current capabilities and limits. Symbolic abstraction then extracts and organizes what was learned into reusable skills, perceptual symbols and rules, so learning transfers to appropriate scenarios instead of being forgotten. Repeating this **dynamic-symbolic** loop yields open-ended growth without external rewards or hand-designed training stages or curriculums (Figure 1).

This research contributes to innovation in next-generation AI fields in three ways. **First,** it enables lifelong development in embodied AI: robots that progress from basic sensorimotor exploration to coordinated movement and then to social interaction, where each stage bootstraps the next—without task-specific programming or a hand-designed curriculum. **Second,** it offers a developmental route to AI alignment, play is where turn-taking, negotiation, and cooperative habits first emerge, so robots can naturally learn these norms through development rather than by having them hard-coded. **Third,** it benefits both engineering and science: developmental robots provides a concrete way to test ideas about human development, while human data helps us build better robots. This direction directly serves JST Moonshot Goal 3: "AI robots that autonomously learn, adapt, evolve in intelligence, and act alongside human beings, by 2050."

2. Research Proposal in the Doctoral program
(**max. 2 A4 pages.** You may use charts and tables. Font size must be 10pt or larger. Do not alter the format or add pages. You can change the allocation for each section within the page limit.)

(1) Describe your research background and current problems, with references provided as appropriate.
Intrinsic Motivation (IM). As deep reinforcement learning and self-supervised world modeling have matured, intrinsic motivation has become a central strategy for moving beyond fixed rewards—supporting exploration and skill acquisition when tasks are sparse, changing, or underspecified [1–5]. Yet three limitations persist. **(i) Statistical**: many IM signals reward prediction error or surprise from an observer-centric stance, rather than being anchored to the agent–world causal interface—what the agent can reliably do to the world, and what the world can do to the agent [2–5]. **(ii) One-sided**: objectives collapse into explore-only novelty chasing or exploit-only local mastery, with no principled mechanism for regime switching [3–6]. **(iii) Non-dynamical**: even hybrid approaches rely on fixed mixtures or hand-designed schedules, so agents lack self-regulated explore–exploit dynamics [4–6]. **This raises an unresolved question: how can intrinsic motivation be formulated so that explore–exploit rhythms emerge endogenously?**

Representation Learning. In parallel, representation learning has shifted beyond supervision toward self-supervised and generative objectives—reconstruction, contrastive prediction, masked modeling—aiming to extract reusable features and structure from high-dimensional sensory streams [7–10]. Yet two limitations persist. **(i) Statistical/mean-seeking:** much unsupervised learning over-rewards compression, summarizing correlations but producing features tied to surface correlations that break when the environment changes—especially in embodied settings where the agent's actions reshape the observed data [8–11]. Representations should be useable and operational: robots should be able to compose, factor, and reuse features as objects and symbols of computation [11–13]. **(ii)Underdetermined:** without explicit selection pressure, representation learning is underdetermined as many possible encodings of perceptual features may fit passive data. Only a few invariant features frame the world into structural invariants stable under transformation and, crucially, for use in robot action [11–14]. **This raises an unresolved challenge: how can representation learning be biased toward useful invariant, symbol-ready features?**

The Missing Integration. Many operational invariants are not identifiable from passive observation; they surface only when an agent actively probes and changes the world [11–14]. Yet no current framework couples a principled oscillatory intrinsic drive—one that generates disciplined action patterns and self-regulated explore/exploit switching—with a structural-invariant learner capable of converting the resulting regularities into reusable operational modules. **Without this integration of Intrinsic Motivation and Symbolic Representation Learning, predictable failure modes arise: intrinsically motivated robots' cycle through behaviors without learning and building up structure, while representation learning converges to underdetermined features not relevant for robot use or control** [4–6, 11–14]. Playful robots have been explored—most notably by Der and Martius's homeokinetic approach [5]—but this method inherits the limitations outlined above. Its prediction-based intrinsic drive is one-sided: it tends toward pure novelty-seeking behaviors that may be active but not meaningful, and it provides little control over the environment. Moreover, lacking any capacity for symbolic abstraction, the agent does not learn or act on new representations—it cycles through behaviors without building reusable features. On the other hand Empowerment only approaches [X] attempt to address controllability by maximizing the agent's influence over the environment. Though promising as it emphasizes casual relations it falls into the opposite trap: locally over-emphasizing exploit at the expense of explore, converging to control without continued development. Neither approach couples a balanced intrinsic drive with operational representation learning. This gap is the core problem motivating this doctoral research.

(2) State your research goals, methods, and target of study.
Goal. ***My research goal is to build a play based developmental robot mechanized as oscillating IM (dynamic bidirectional engagement) and symbolic feature extraction capabilities.*** The robot (i) acts on the world through intrinsic motivation grounded in the agent–world causal interface, (ii) extracts operational invariants (stable, reusable features) —via algebraically constrained representation learning. These features are selected and recomposed for satisfying the intrinsic motivation (increasing both control and sensitivity). The robot will then (iii) projects those invariants back as new control targets, enabling continued refinement and abstraction of learned features. Such a robot will develop increasingly intelligent and sophisticated ways of engaging with the environment. Because intrinsic drive and representation learning are integrated, the robot will generate its own curriculum by engaging with the world at the level of its own competence—no external hyper specific task-based reward, no hand-designed stages*. This ensures a robot with open-ended autonomy that undertakes meaningful actions with useful representations rather than random environmental exploration or static data compression.*

Method. The method has two core components and their integration.

- **Empowerment-Plasticity oscillation (new intrinsic motivation: E-P).** In 2025 a new potential intrinsic motivation, the dual of empowerment/control was published by Abel called Plasticity/Sensitivity. By implementing both *empowerment* (agent → world, influence) and *plasticity* (world → agent, sensitivity) simultaneously I will implement a new principled intrinsic motivation for developmental robots. The principled symmetric tension of the oscillating pair (empowerment & plasticity) will produce an endogenous explore-exploit rhythm (perturb → observe → update → re-perturb). This directly addresses the three limitations identified in **(1)- i, ii & iii** : it is causal (interface-grounded, not observer-centric), two-sided (avoids explore-only or exploit-only collapse), and dynamical (self-regulated regime switching without fixed schedules).

- **Algebraic constraint learning (representation).** Rather than optimizing purely statistical objectives (reconstruction, compression), I will apply Ohmura's algebraic constraint learning to bias feature discovery toward factors that satisfy algebraic structure—group-theoretic decomposition that separates conditionally independent transformations. This resolves the **(i) Statistical/mean-seeking problem** outlined in **(2)** by producing invariance under transformation and representations that are operational and naturally discretizable (symbol-ready for use by the robot), rather than latents tied to surface correlations.

- **Integration (developmental loop).** E-P IM will supply disciplined actions and and the missing selection pressure—prioritizing feature invariants that expand both controllability and sensitivity satisfying the new E-P IM, hence resolving the **(ii)Underdetermined problem** outlined in **(2)**. Algebraic constraints convert interaction-revealed regularities into reusable modules. Crucially, once modules become operational abstractions, the agent projects them back into control: it sets references over them, composes and manipulates them, and the E-P IM continues oscillating at this higher level to refine and reorganize the symbolic inventory over time.

- **Target of study**. I will instantiate this framework in robots (simulation then physical robots) on tasks where passive data is insufficient and distribution shift is common: object interaction, manipulation, and skill acquisition under changing dynamics. The primary simulator platform is **the ISI Baby Simulator infant body** model which will be used to track common infant developmental milestones (self-touch, hand-regard, reaching then tool use). The target outcome is a robot that after learn how to control its own body will be able to use tools to interact with its environment and develop social cognition by playing with humans and robots.

(3) Explain the defining characteristics of your research, what makes it original, and/or what impacts it will have when it is completed.

Originality and Impact. Three characteristics define this research: (1) deep integration of developmental psychology and developmental robotics—the intrinsic drive formalizes Trevarthen's play and Piaget's equilibration, representation learning draws on Piagetian algebraic structure, and simulations are benchmarked against actual infant developmental stages, enabling genuine bidirectional exchange between fields; (2) the coupling of intrinsic motivation and representation learning is novel, as prior work treats these as separate problems and this separation is why both fail; (3) the intrinsic drive which allows for self-generated curriculum is architecturally novel, plasticity is not a bonus term but a symmetric pairing (empowerment ↔ plasticity) whose tension produces endogenous regime switching; If successful, this research contributes to representation learning (operational invariants, not compression codes), intrinsic motivation (a new architecture addressing one-sided and non-dynamical limitations), developmental psychology (computational models that transform description into causal mechanism), and robotics (open-ended autonomy serving Moonshot Goal 3). Ultimately, play is the developmental origin of morality—and this research points toward a future where robots and humans coexist through shared foundations built from play.

(4) Give details on your plans, including what you intend to uncover and to what extent.

Year 1: I will implement E–P oscillation (empowerment–plasticity intrinsic drive) and couple it with algebraic constraint learning, testing on **the ISI Baby Simulator benchmarked** against infant developmental **milestones (self-touch, hand-regard, reaching**). The goal is to demonstrate that coupling intrinsic motivation and representation learning produces developmental trajectories—characterized by E–P regime shifts—that single-objective methods cannot achieve.

Year 2: I will scale to object manipulation and early tool use, demonstrating the developmental loop closing: learned invariants become symbolic control targets, and E–P oscillation continues at higher levels of abstraction. I will also test robustness under morphological and environmental change.

Year 3: I will extend to multi-agent settings to investigate whether play-driven development produces foundations for social cognition and cooperative behavior, and complete the theoretical synthesis connecting the framework to AI alignment.

3. Research Background

(**max. 1 A4 pages**. You may use charts and tables. Font size must be 10pt or larger. Do not alter the format or add pages. You can change the allocation for each section within the page limit. If nothing applies, indicate "None".)

(1) Describe your research up to the present point. You may include your graduation project, and studies equivalent to such projects (e.g. Special Experiments, Theoretical exercises)

My research investigates the formal and computational foundations of agency, with particular focus on how control-theoretic agents develop structured representations through interaction with the world. My masters thesis, "Cybernetic Mimesis: Collective Phenomena through Reference Imitation among Feedback-Control Agents," represents a deep integration of robotics, control theory, and developmental psychology. The work examines how feedback-control agents, coupled through reference imitation, produce emergent collective dynamics—grounding social behavior in ideomotor theory, where actions are initiated by anticipating their perceptual consequences. This bridges Perceptual Control Theory with developmental accounts of imitation, demonstrating that collective behavior can arise without explicit coordination. This interdisciplinary approach—unifying engineering and psychological perspectives on agency—was published at ALIFE 2025 and received the **Rising Star Award** for outstanding contribution to the artificial life community.

Formalizing agency. In collaboration with Ohmura and Kuniyoshi, I co-authored "A Mathematical Formalization of Self-Determining Agency," providing a formal account of self-determination through supervenient causation. This directly informs the proposed doctoral work: the Empowerment-Plasticity framework extends this formalization. **Developmental psychology connection.** I presented "Algebraic Structural Feedback Control and Genetic Epistemology" at the Jean Piaget Society 2025 (Belgrade), establishing Piagetian foundations for the proposed representation learning approach. I also presented "Agency as the Evaluation of Structure" at ECogs 2025 (Okinawa).

(2) Presentations given at conferences and symposia, both domestic and international (Divide your list into oral and poster, as well as reviewed and non-reviewed, presentations, and mark them accordingly.)

Earnest Kota Carr; et al. 「Cybernetic Mimesis: Reference Imitation Driven Collective Behavior」ALIFE 2025 (Conference on Artificial Life), Kyoto, Japan, July 2025.

Earnest Kota Carr; Ohmura, Y.; Kuniyoshi, Y. 「知覚同化の計算モデル：代数的構造フィードバック制御と遺伝的認識論 / Algebraic Structural Feedback Control and Genetic Epistemology」Jean Piaget Society Annual Meeting 2025, Belgrade, Serbia, June 2025.

Poster presentations (peer-reviewed)

Earnest Kota Carr; Ohmura, Y.; Kuniyoshi, Y. 「Agency as the Evaluation of Structure: Embodied agency as constructivism, not (mere) constructionism」poster #31 ECogs 2025, Okinawa, Japan, March 2025.

Earnest Kota Carr; Ohmura, Y.; Kuniyoshi, Y. 「Mechanizing and Formalizing Self-Determining Agency」poster #45 ELSI 14th International Symposium, Tokyo, Japan, January 2026.

(3) Papers published in academic journals and books (You may list only those works which have been printed or already been accepted for publication. Divide your list into reviewed and non-reviewed publications.)

Earnest Kota Carr; et al. 「Cybernetic Mimesis: Reference Imitation Driven Collective Behavior」Proceedings of the 2025 Conference on Artificial Life (ALIFE 2025), MIT Press, 2025. (https://direct.mit.edu/isal/proceedings/isal2025/37/82/134095)

(4) Other (e.g. awards)
ALIFE 2025 Rising Star Award: Outstanding early-career contribution to the Artificial Life community
AI センター：融合研究推進基金 2024 年度「模倣学習による適応フィードバック制御系の合成」2024 年
Builders Weekend 2024 Hackathon Tokyo
UTEC 2021 research grant

Proof of Awards

ALIFE 2025 Rising Star Award: Outstanding early-career contribution to the Artificial Life community

AI センター：融合研究推進基金 2024 年度「模倣学習による適応フィードバック制御系の合成」2024 年

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AIセンター融合研究促進費の採択結果について（カー　アーネスト航太 殿）
46 件のメッセージ

AIセンター事務局 <ai-sec@ai.u-tokyo.ac.jp>　2024年9月24日 12:09
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Cc: director@ai.u-tokyo.ac.jp

2024年9月24日

情報学環・学際情報学府
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次世代知能科学研究センター長
國吉　康夫

2024年度ＡＩセンター融合研究促進費の採択結果について

標記の件につきまして、貴殿におかれましては、以下のとおり採択されましたのでお知らせいたします。

記
テ ー マ 番 号：3

研　究　題　目：模倣学習による適応フィードバック制御系の合成

採　択　金　額：1,100,000円

なお、2025年12月末までにA4 1ページ以内の報告書（成果、進捗経緯、発表実績・予定、予算使途等）を提出頂きます。
また、一定期間後、当センターの報告書に記載可能な成果発表情報を再度お問合せすることがあります。
本予算が寄与した成果の発表時には、「東京大学次世代知能科学研究センター」または「東京大学AI センター」への謝辞の記載（他予算等と併記可）をお願いします。

※採択金額を代表者研究費へ配分いたします。
所属部局以外の兼務先部局等での執行を希望される場合には、【9月30日（月)】までに、director@ai.u-tokyo.ac.jp 宛にご連絡ください。

以上

【本件担当】
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