Implementation of Structured Memes into Behavioral Ecology via GOMS

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A Short Resume of the Presenter

Muneo Kitajima is currently a professor emeritus at Nagaoka University of Technology. His recently published book "Memory and Action Selection in Human-Machine Interaction" (2016) proposes a unified theory of action selection and development by integrating PDP, Two Minds, and layered structure of human action. The theory provides a comprehensive view of how our brain functionally works in our daily life. His current interest is to understand the implications of the theory to development of skill of adaptive problem solving, the important skill for survival.

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Abstract

- Our daily actions are executed to achieve desired states. Perceiving our own situation, we select actions that are expected to bring about the desired states, and execute them as a series.
- The memory used in this process is a representation in the brain of memes that are inherited from generation to generation. Memes are structured into three levels: action level, behavioral level, and cultural level, and are acquired through mimetic behavior. Memes at the higher levels are acquired as one gets older.
- This study is based on the Model Human Processor with Real-Time Constraints (MHP/RT), a cognitive architecture that includes Perceptual, Cognitive, and Motor (PCM) processes, and a memory system that is used during action selection by the PCM process and updated after action execution.
- *We examine how the cognitive process of Two Minds utilizes memes structured in three layers, which is referred to as C-resonance in MHP/RT.*
- It is known that knowledge built as a result of iterative actions toward a goal state is represented by a GOMS hierarchical structure whose elements are goals (G), operators (O), methods (M), and selection rules (S).
- This study shows that GOMS bundles memes belonging to different levels and combines goals and selection rules at the conscious level with methods and operators at the unconscious level to achieve effective and efficient goal-oriented action execution.
- *The expressed behavior can be regarded as the result of crossing the syntax expressed by GOMS with the semantics expressed by memes, showing distinct characteristics depending on the balance of dominance between unconscious and conscious behavior in the behavioral ecology.*

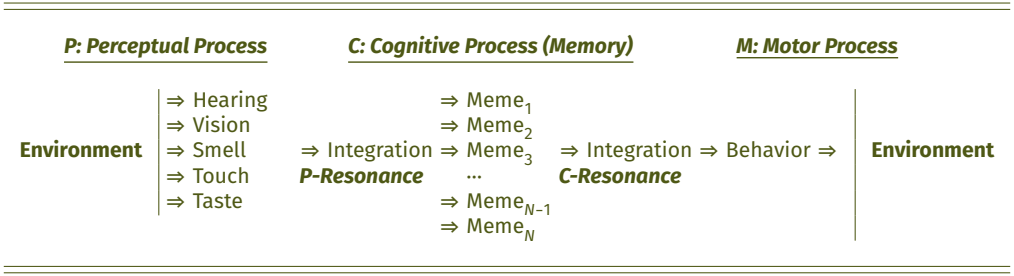
Meme Proposed by Dawkins [1]

- The mechanism by which cultures and civilizations produced by humans are passed on from generation to generation was not clear.
  - From the standpoint of cultural anthropology, Dawkins organized his research on the mechanisms of cultural inheritance. As a result, he argued that cultural inheritance cannot be explained solely in terms of the capability of memory on the part of humans, and that there must be a hypothetical existence on the part of culture that might convey information, such as genes.
- He coined the term “meme” for this indefinite virtual entity [1]. This idea itself received a lot of support, but the time passed without the mechanism being clarified [2].
- When Dawkins proposed the meme, the function of genes was not yet understood. Therefore, Dawkins’ explanation and others had many problems inherent in them due to misunderstandings about genes.
  - Certainly, genes were replicators. However, they did not play the role of duplicating the blueprint of the finished product as conventionally thought, but rather, they played the role of plotting the process of growth that established the basic functional structure and its relationships. It was this role of the genes that enabled humans to be highly adaptable.

Redefinition of Dawkins’ Meme

- The memes proposed by Dawkins can be redefined by considering them as mappings of the individual’s memory (which can be called *the individual ecological memes*), which is activated in the process of selecting and executing actions, onto *the collective ecology* that caries the culture.
- Memes are realized in the memory of each individual.
- They hold the relationships between events, which enable humans in an ever-changing environment to express effective behavior in each situation in generic forms that are valid across generations [3].
- More specifically, the spatial coordinates and absolute times that characterize events occurring in the real world are *not* retained in the memes; they are dynamically determined according to the state of the environment when the behavior is expressed according to the representation of the memes.

Schematic Representation of the Action Selection and Execution Process in the Real Environment as a PCM process



PCM Process:

- ***Perceptual Process:*** Humans perceive the state of the real environment through parallel processing of the five senses and integrate what they perceive individually by binding them.
- ***Cognitive Process:*** The memes related to the perceived information are activated in parallel, and they are integrated as a series of operators that can be executed as concrete actions in the environment.
- ***Motor Process:*** The operators are executed unconsciously through feedforward processing, keeping pace and synchronizing with changes in the environment.

Connecting PCM Process and Memory by Means of P- and C-Resonance:

- The PCM process runs synchronously with the environment, whereas, the "memory system" used by the PCM process updates itself asynchronously with the environment to reflect the results of the PCM process. Supported by the PCM process and the memory system, each individual repeats action selections in an ever-changing environment without any breakdown.
- In this regard, it is important to clarify the interface between the PCM process, which operates synchronously with the environment, and the memory system, which is not required to synchronize with the environment but is connected to the PCM process.
  - ⇒ *The mechanism for connecting what is perceived with memory has been described as* ***P-resonance*** *[4].*
  - ⇒ *Within the memories, structured with memes as elements, activation propagates in parallel with the integrated perceptual information as the activation source. Connecting activated memories to the actions performed in the real world, i.e., "enabling the activated memes in the real world by integration." This mechanism is shown as* ***C-resonance****. How is this done?*

GOMS is the Key

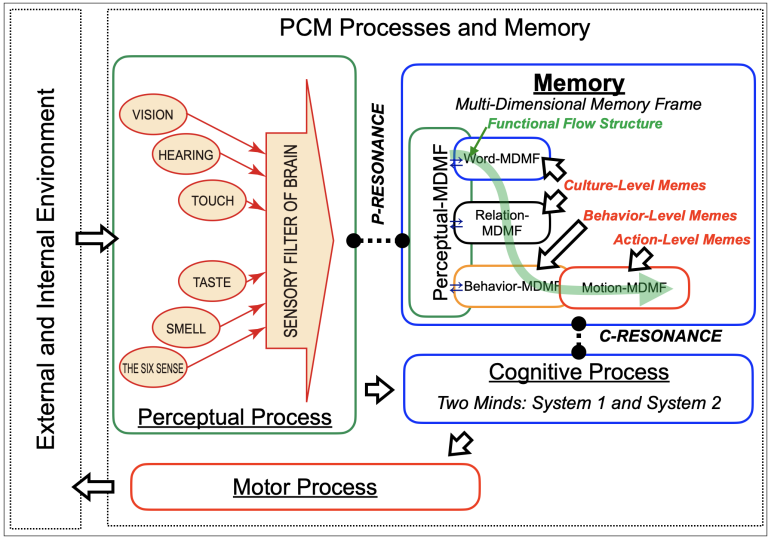
- When we unravel the origin and evolution of life, we can find a clue to the solution.
- Life is formed under the structures shaped by the atmosphere, oceans, energy cycles, and gravity that characterize the Earth, a planet in our solar system, spinning on its own axis and orbiting the Sun. The direction of life's evolution is determined by the pressures exerted by these structures.
- Life is formed as an adaptive body with the functional and structural feature that work most efficiently in the environment.
- It is best captured by the four elements of Goals, Operators, Methods, and Selection rules (GOMS) [5].
- GOMS specifies concepts that define a meta-structure that is essential for understanding the ecology of human behavior.

Outline of GOMS

GOMS specifies that the user's cognitive structure consists of four components: (1) a set of Goals, (2) a set of Operators, (3) a set of Methods for achieving the goals, and (4) a set of Selection rules for choosing among competing methods for goals, each of which is defined as follows (adapted from [5, pp.144–146]):

- ***Goals***. A goal is a symbolic structure that defines a state of affairs to be achieved and determines a set of possible methods by which it may be accomplished.
- ***Operators***. Operators are elementary perceptual, motor, or cognitive acts, whose execution is necessary to change any aspect of the user's mental state or to affect the task environment.
- ***Methods***. A method describes a procedure for accomplishing a goal. It is one of the ways in which a user stores his knowledge of a task. The description of a method is cast in a GOMS model as a conditional sequence of goals and operators, with conditional tests on the contents of the user's immediate memory and on the state of the task environment.
- ***Selection Rules***. When a goal is attempted, there may be more than one method available to the user to accomplish the goal. In a GOMS model, method selection is handled by a set of selection rules. Each rule is of the form "if such-and-such is true in the current task situation, then use method M."

In this study, we show that C-resonance, which integrates the memes activated in parallel as the effective actions in the real world, can be explained by the GOMS concept.



PCM Processes and Memory:

- *PCM Processes and Memory* shown above is based on the Model Human Processor with Realtime Constraints (MHP/RT) [6, 7], by which environmental information is taken into the body via sensory nerves, processed in the brain, and then acted upon by the external world via motor nerves.
- PCM processes use memory, modeled as Multi-dimensional Memory Frame (MDMF), consisting of Perceptual-, Behavior-, Motor-, Relation-, and Word-Multi-dimensional Memory Frame, abbreviated as P-, B-, M-, R-, and W-MDMF, respectively.

Features of MHP/RT and MDMF:

- P-MDMF overlaps with B-, R-, and W-MDMF; this unique configuration supports spreading activation from P- to M-MDMF, which connects perception with bodily movements.
- Perceptual information *resonates* with information in MDMF, called P-Resonance.
- In the cognitive process, conscious process utilizes W- and R-MDMF via C-Resonance, and unconscious process utilizes B- and M-MDMF via C-Resonance.
- The motor sequences are expressed according to M-MDMF.

Memory Organized as Memes: The basis of behavior is *imitation*; Behaviors that can be imitated across generations are preserved as sustainable behaviors. In this way, we can organize MDMF, which is used by the PCM processes and updated by their execution, in terms of *memes* that can be inherited across generations [8], in the following three levels of memes:

- *Action-Level Memes (A-memes)* represent bodily actions stored in M-MDMF.
- *Behavior-Level Memes (B-memes)* represent behaviors in the environment stored in B-MDMF.
- *Culture-Level Memes (C-memes)* represent culture stored in the R- and W-MDMF.

The objects in the environment activate A-, B-, and C-memes. In this activation process, various regions related to the objects are activated. In the Figure on slide 6, the propagation of activation within MDMF is shown as the functional flow structure. The detail of this activation process is described below:

Spreading Activation in MDMF via P-MDMF

- The activity propagates from P-MDMF to W-, R-, B-, and M-MDMF in that order.
- The layers below W-MDMF are not structurally overlapped; The activity propagates layer by layer from the top to bottom via P-MDMF that overlaps with them.
  - At the top, there is an activation flow from W- to P-MDMF,
  - At the middle from P- to R-MDMF, and
  - At the bottom from P- to B-, finally to M-MDMF.

The portions of W-, R-, and B-MDMF that are activated in this manner may contain multiple regions that may be related via P-MDMF but not directly related to each other.

Meme Binding Problem (MBP)

- Memories that hold A-, B-, C-Memes are activated in parallel to be used by the PCM process, which is a serial process.
- Here, we can see another binding problem occurring at the cognitive level.

Resolving MBP by C-Resonance

- In the Figure on slide 6, the bridge between cognitive and memory processes is shown as C-resonance for resolving the meme binding problem.
- The cognitive process might operate *carefully* by using the entire areas of MDMF that are activated in connection with P-MDMF.
- The advantage of this method is that reality can be guaranteed by referring to the contents active in P-MDMF.
- However, it is *inefficient* because it is an interpreter-like process.
- At the perceptual level, the binding problem of perceptual information is solved by P-resonance for effective use of the perceptual information.
- At the cognitive level, C-resonance resolves the problem of efficient use of memory by binding memes somehow that are activated in parallel [9].

What is the equivalent of the basic senses in P-resonance in C-resonance?

Action Execution Based on GOMS

- In GOMS, behavioral goals form a robust hierarchical structure, and the goal structure mediates the organization of behavior.
- Achieving a goal, G, requires achieving the subgoals underneath it, G's.
- This structure does not hold the time as its primary parameter. The order between G's is important.
- The time elapsed for executing G' is associated with the operators located at the bottom layer, which connect to the motor process of PCM that implements the contents of M-MDMF, i.e., the operators, in the real world.

Action Execution Based on MHP/RT and Memes

- As shown in Figure shown in slide 6, the environment is perceived and connected to the MDMF by P-resonance. Then, as shown in Figure shown in slide 6, the memes having been acquired by structuring the MDMF through experience are activated, and the A-memes are connected to the real world to execute the action.
- As mentioned earlier, in the functional flow structure within the MDMF shown in Figure on slide 6, behavior generation following the flow of activity through the P-MDMF is inefficient.

Integrating GOMS and MHP/RT with Memes

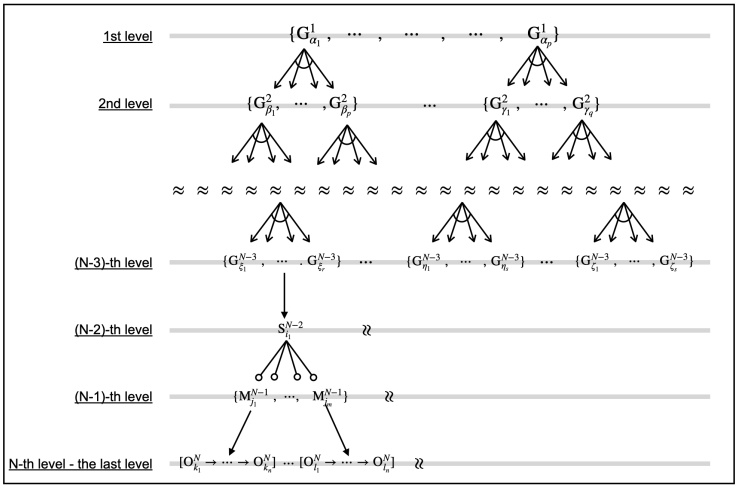
- It is reasonable to assume that GOMS is used to structure A-, B-, and C-memes that do not contain absolute temporal and spatial information as a method of realizing behavior generation without breaking down, while keeping in sync with the real world where the situation changes from moment to moment.
- GOMS should correspond to the phenomenon of A-, B-, and C-memes binding without the P-MDMF when encountering certain situations, indicating the entity of the phenomenon of C-resonance.
- This may correspond to a shortcut that may be formed within the MDMF.

Relation between GOMS, Memes, and Two Minds – The Correspondence between Memes and GOMS

Activation of Memes via P-Resonance			Utilization of Memes via C-Resonance	
Perceptual Process	Multi-dimensional Memory Frame	Memes	GOMS	Cognitive Process
Basic Senses	Word- & Relation-	Culture-Level	Goals and Selection Rules	System 2
	Behavior-	Behavior-Level	Methods	System 1
	Motor-	Action-Level	Operators	System 1

Among the activated memes, the combinations of C-, B-, and A-memes that have formed GOMS bonds in the process of gaining experience are processed by System 2 and System 1, and the operator sequence is executed in the real world [10].

The Overall Picture of GOMS-Construct



- $\mathbf{O} = [O^N_{k_1} \rightarrow \cdots \rightarrow O^N_{k_n}]$: Operator sequence at the N-th layer
- $\mathbf{M} = M^{N-1}_{j_1}$: Method at the $(N-1)$-th layer
- $\mathbf{G_i} = G^{N-3}_{\xi_i}$: Goal at the $(N-3)$-th layer; Above the $(N-3)$-th layer, a hierarchical goal structure develops.
- $S^{N-2}_{i_1}$: Selection rule at the $(N-2)$-th layer if there are multiple methods, $\{M^{N-1}_{j_1}, \cdots, M^{N-1}_{j_m}\}$, that can achieve $\mathbf{G_i}$
- The goals located at the top level $\mathbf{G^1_i} = G^1_{\alpha_i}$ are expanded into a set of goals, $\mathbf{G^2} = \{G^2_{\beta_1}, \cdots, G^2_{\beta_p}\}$, at the second layer, and $\mathbf{G^1_i}$ is achieved by the achievement of all goals contained in $\mathbf{G^2}$.

- Individual G, O, M, S nodes are pointers to A-, B-, and C-memes. In the real situations, efficient use of memory is requited for smooth operation of the PCM process.

⇒ *There should be an upper bound on the total number of G-, O-, M-, S-nodes available in C-resonance mediated by the GOMS structure.*

- $\hat{G}$: the total number of goals
  $\hat{M}$: the total number of methods
  $\hat{S}$: the total number of selection rules
  $\hat{O}$: the total number of operators
  $\bar{N}$: the average depth of the hierarchy
  $\hat{C}$: the upper bound on the number of nodes
- Let's start considering variations in the overall picture of GOMS-construct through experience under the condition, $\hat{G} + \hat{O} + \hat{M} + \hat{S} \leq \hat{C}$.
  - Since the operator is an elemental part of the construction of the method, $\hat{O}$ is presumed to be much smaller than $\hat{C}$, i.e., $\hat{O} \ll \hat{C}$.
- *How are the G-, M-, and S- nodes used?*
  - A method is a kind of goal that can be executed by the operators, so that the elements of the set of operators can be used as material to achieve the lowest goal that has been developed.
  - If there are multiple methods that can achieve the goal, one method is selected based on the selection rule that defines the conditions for application of the method.

For an event $E(T)$ that occurs at time T, MHP/RT deals with it in its four processing modes [7].

- **System-2-Before-Event-Mode**, which consciously considers $E(T)$ beforehand,
- **System-1-Before-Event-Mode**, which unconsciously adjusts its behavior to the environmental context immediately before $E(T)$,
- **System-1-After-Event-Mode**, which unconsciously adjusts the connections within the relevant P-, B-, and M-MDMF immediately after $E(T)$, and
- **System-2-After-Event-Mode**, which consciously reflects on $E(T)$ afterwards to adjust the connections within R- and W-MDMF.

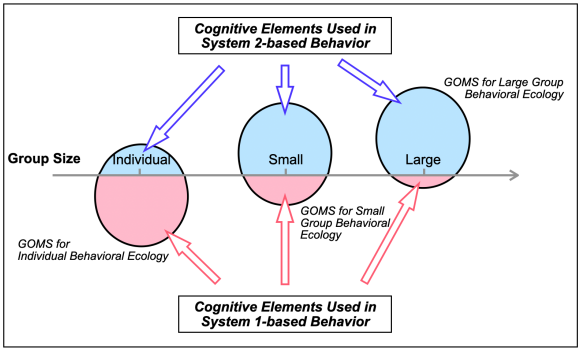
The GOMS-construct that each individual has developed should reflect
– the results of action selection in the System-1-After-Event-Mode and System-2-After-Event-Mode
– using the A-, B-, and C-memes in the System-2-Before-Event-Mode and System-1-Before-Event-Mode.

- By allocating more resources to System-2-After-Event-Mode, he or she can construct a richer goal structure, which allows System-2-Before-Event-Mode to devote more resources to making accurate and reliable predictions in a variety of future situations he or she encounters.
- On the other hand, a sequence of methods involving successively occurring events, $E(T), \cdots, E(T+n)$, can be integrated into a single method by allocating more resources to System-1-After-Event-Mode.
  - The integrated specialized method generates a specialized operator sequence for the corresponding sequence of events.
  - In facing a variety of situations, the number of specialized methods will increase.
- Due to the limited processing capacity of the brain, either System-2-After-Event-Mode or System-1-After-Event-Mode will become dominant.
- Therefore, the following is predicted concerning the shape of GOMS-construct:
  - ***If System-2-After-Event-Mode is dominant, then a goal-rich GOMS-construct, $\hat{G} \gg \hat{M}$, will be constructed.***
  - ***If System-1-After-Event-Mode is dominant, then a method-rich GOMS-construct, $\hat{G} \ll \hat{M}$, will be constructed.***

Relationship between the Number of GOMS Components and the Balance of Conscious/Unconscious Processing

This figure shows that the balance between System-1-After-Event-Mode-dominance and System-2-After-Event-Mode-dominance changes depending on the range of communities that the individual is directly and indirectly involved in during his/her life.

- ***Left***: In a behavioral ecology where individuals rarely interact, each individual can lead a sufficiently problem-free life by having a set of methods that are specific to the situations he or she encounters. Therefore, the relation, $\hat{M} \gg \hat{G}$, holds; most actions are generated through unconscious execution of methods by System 1.
- ***Middle***: In the case of community-based living, each individual is expected to act according to the way he or she functions within the group he or she belongs to. When communication among group members is established in surface language, individuals are unable to perform elaborate inferences. Therefore, the relationship, $\hat{G} > \hat{M}$, is established.
- ***Right***: When a group belongs directly to a community and that community constitutes a society and/or when communication is done in structural language, the behavioral ecology becomes System-2-After-Event-Mode-dominant and the relationship, $\hat{G} \gg \hat{M}$, is established; the individuals can respond to various situations flexibly by allocating resources to the execution of System-2-Before-Event-Mode with careful use of the well-developed goal structure.



- This figure also shows the change in the GOMS-construct as the size of the group changes under the constraint $\hat{C}$ is limited.
  - As the social relationships increase, $\hat{M}$ decreases through the reorganization of the goal structure by abstracting multiple individualized methods together.
  - Meanwhile, the number of System 2 elements increases as the complexity of the relationship increases; by shifting to a behavioral ecology in which System 2 elements are more important than System 1 elements, the composition of elements in the entire GOMS will change to a composition with a rich goal structure that allows for more logical thinking.

The existence of memes is a prerequisite for the generation of GOMS. GOMS also plays an important role in efficient action generation. The generated actions update MDMF and contribute to meme formation. Thus, GOMS and memes are in a mutually developing relationship. Actions are generated in two ways: driven by System 1 or driven by System 2. The bias, i.e., the dominance of System 1 or System 2, in the generation of action, should affect the aspect of mutual development.

A-, B-, and C-Memes

- A- and B-memes involve physical behaviors that are executed by connecting P-, B-, and M-MDMF.
  - Since A-memes are elemental in generating behavior and B-memes are combinations of elements of A-memes, they are different in granularity and do not mix with each other.
  - The content of the inherited memes is almost invariant, since the content of physical behavior does not change significantly over time.
- C-memes, on the other hand, are disconnected from physical behavior.
  - It includes language activities with linguistic symbols and inference through the application of rules.
  - W- and R-MDMF are used for these activities. Linguistic symbols and rules are gradually updated under the influence of the social and natural environment surrounding each generation.
- A-, B-, and C-memes exist in parallel, without mixing with each other, and each is inherited from generation to generation.

Memes as Semantics and GOMS as Syntax

- GOMS covers orthogonally to the parallel meme structure and allows A-, B-, and C-meme elements to be combined with each other to efficiently generate effective actions in response to the real-world situations.
  - This is accomplished by combining the elements in MDMF in the form of a GOMS-construct.
- Since words are typical of memes, we can regard memes as carriers of meaning, i.e., *semantics*.
- GOMS can be thought of as *syntax* because it specifies how words are combined together.

Mutual Development of GOMS and Meme (2)

C-memes represent inherited cultures, which are diverse. Based on the discussion in the previous slide, we can broadly distinguish between cultures that are rich in the goal structure of GOMS, G-culture, and cultures that are rich in the variety of methods, M-culture.

G-Culture vs. M-Culture and Updating Memes

- Individuals acting in each culture acquire and act upon the inherited memes of that culture.
- The memes in the G-culture might be updated through System-2-After-Event-Mode, whereas those in the M-culture might be updated through System-1-After-Event-Mode.
- In either case, if the meme is deemed valid within the population in the updated structure, it will trigger a meme update.
- The update of a meme requires time for validation. Thus, it does not mean that the meme will be updated immediately.

The Corporeality of the Goal

- Since a GOMS-construct links goals and operators, it guarantees corporeality for the goals present in the W- and R-MDMF.
- This ensures that even in the G-culture, the development of GOMS for various goals does not dissociate them from the real world.
- In other words, the connection of the W- and R-MDMF, to which G belongs, with B- and M-MDMF, to which M and O belong, guarantees the corporeality of the goal, G.
- ***By applying the GOMS-construct to memes, it is possible to make the meme, which is not linked to the real world as it stands, not free from the real world.***

Common Understanding of Words and GOMS

- Words are a typical example of memes [11] and the elements of C-memes.
  - Words are the primary communication medium and are passed on from generation to generation [3].
  - Individuals make sense of words and understand the situation by referring to the context in which the words have been uttered.
  - However, individual members of a community that share a C-meme may not assign a common meaning to a particular word, even when placed in a common context [9].
- The number of words known by native English-speaking adults is 20,000~30,000, and the number of words used in daily conversation is 3,000~4,000.
  - Conceptually known words are inherited as the elements of C-memes.
  - However, the words used in daily activities unite the C-meme with the B- and A-memes, which are associated with corporeality, by means of GOMS.

The goals in GOMS represented by symbols belonging to C-memes are developed into the operators of GOMS belonging to A-memes, and the meaning of goals can be shared as B-memes as a sequence of operators, i.e., the methods of GOMS, that can be superficially observed as they carry out their daily activities.

Number of Top Located Goals and Behavioral Ecology

- Recently the characteristics of societies that rely on *strong kinship* relations and those in which *individualism* is prevalent have been discussed [12].

⇒ In the societies where C-memes reflecting strong kinship are inherited, the number of goals that can exist is limited, forming the System 1-driven behavioral ecology.

⇒ In the societies with advanced individualism, each individual constructs his/her own goal structure, forming the System 2-driven behavioral ecology.

- In the societies with advanced individualism, many elements are used to construct the goal structure, and flexible action selection is achieved by replacing the higher-level goals depending on the situation.
  - Since the replacement of the topmost happiness goal also occurs, the behavior is executed by switching between GOMS structures; *a manifestation of the modalization of behavior*.
- Modalization of behavior results in the appearance that an individual switches his or her behavioral norms depending on the situation.
  - This does not necessarily guarantee that even if the same operator sequence is observed, the goal structure developing on top of it is unique.
  - The possibility of misunderstandings arising from this cannot be excluded; *The problems inherent in an individualistic society will appear here*.

GOMS as the Mechanism of C-resonance

- In MDMF, there are memes, which are A-, B-, and C-memes, structured by three hierarchies. These memes are mapped to each memory in MDMF and are linked to each other by sharing P-MDMF. For this reason, reality is ensured by perceptual information.
- On the other hand, C-resonance works under a time-constrained situation in which the PCM process must select and execute actions while synchronizing with changes in the environment, and connects MDMF and cognitive processes.
- In this study, we introduced GOMS as the mechanism to link W-, R-, B-, and M-MDMF directly, without going through the P-MDMF.
- Each element of GOMS is represented as a node in the brain. The finite number of nodes that can be kept allows different behavioral ecologies to emerge depending on how the number of nodes allocated to goals and selection rules operated by System 2 and the number of nodes allocated to methods and operators operated by System 1 are balanced.

GOMS and Behavioral Ecology

- Regarding the C-memes, we examined the characteristics of behavioral ecology in the societies characterized by strong kinship, which inherit simple goal structures, and in the societies with a strong individualistic flavor, which inherit complex goal structures.
- Although the former is not expected to be flexible in action selection, it can achieve effective and efficient action selection and execution in stable social situations.
- In the latter, on the other hand, a modalized goal structure is maintained to cope with various situations, and the individual flexibly switches to the appropriate goal structure while selecting and executing actions.
- We also pointed out that although actions are observed as operator sequences, they are prone to communication errors caused by the non-uniqueness of the goal structure that develops on top of them.

The memes determine the content of the action. The PCM processes determine how to act. The GOMS structure intersects them. By viewing behavioral ecology from the perspective of GOMS, this study showed that static memes can be implemented and brought to life in behavioral ecology. Behavioral ecology is created by living organisms. On the basis of MHP/RT, the manifestation of memes in behavioral ecology has been clarified in the case studies [13, 14]. This study is positioned as a proposal for a method to give life to static digital information while building on the results of these case studies.

[1] Richard Dawkins. ***The Selfish Gene.*** Oxford University Press, New York City, 1976.

[2] Robert Aunger, editor. ***Darwinizing Culture: The Status of Memetics As a Science.*** Oxford Univ Pr on Demand, 1 2001.

[3] Muneo Kitajima, Makoto Toyota, and Jérôme Dinet. **How Resonance Works for Development and Propagation of Memes.** *International Journal on Advances in Systems and Measurements*, 14:148–161, 2021.

[4] Muneo Kitajima, Makoto Toyota, Jérôme Dinet, Anissa Bystrzycki, Anne-Marie Eby, and Marie Gérard. **Basic Senses and Their Implications for Immersive Virtual Reality Design.** In *AIVR 2024 : The First International Conference on Artificial Intelligence and Immersive Virtual Reality*, pages 31–38, 2024.

[5] Stuart K. Card, Thomas P. Moran, and Allen Newell. ***The Psychology of Human-Computer Interaction.*** Lawrence Erlbaum Associates, Hillsdale, NJ, 1983.

[6] Muneo Kitajima. ***Memory and Action Selection in Human-Machine Interaction.*** Wiley-ISTE, 2016.

[7] Muneo Kitajima and Makoto Toyota. **Decision-making and action selection in Two Minds: An analysis based on Model Human Processor with Realtime Constraints (MHP/RT).** *Biologically Inspired Cognitive Architectures*, 5:82–93, 2013.

[8] Makoto Toyota, Muneo Kitajima, and Hideaki Shimada. **Structured Meme Theory: How is informational inheritance maintained?** In B. C. Love, K. McRae, and V. M. Sloutsky, editors, *Proceedings of the 30th Annual Conference of the Cognitive Science Society*, page 2288, Austin, TX, 2008. Cognitive Science Society.

[9] Muneo Kitajima, Makoto Toyota, Jérôme Dinet, Clelie Amiot, Capucine Bauchet, and Hanna Verdel. **Language and Image in Behavioral Ecology.** In *COGNITIVE 2022 : The Fourteenth International Conference on Advanced Cognitive Technologies and Applications*, pages 1–10, 2022.

[10] Muneo Kitajima, Jérôme Dinet, and Makoto Toyota. **Multimodal Interactions Viewed as Dual Process on Multi-Dimensional Memory Frames under Weak Synchronization.** In *COGNITIVE 2019 : The Eleventh International Conference on Advanced Cognitive Technologies and Applications*, pages 44–51, 2019.

[11] Daniel C. Dennett. ***From Bacteria to Bach and Back: The Evolution of Minds.*** W W Norton & Co Inc, 2 2018.

References II

[12] Joseph Patrick Henrich. ***The weirdest people in the world: How the west became psychologically peculiar and particularly prosperous*.** Picador: Farrar, Straus and Giroux, 2021.

[13] Muneo Kitajima, Makoto Toyota, and Jérôme Dinet. **Art and Brain with Kazuo Takiguchi - Revealing the Meme Structure from the Process of Creating Traditional Crafts -.** In *COGNITIVE 2023 : The Fifteenth International Conference on Advanced Cognitive Technologies and Applications*, pages 1–10, 2023.

[14] Katsuko T. Nakahira, Muneo Kitajima, and Makoto Toyota. **Understanding Practice Stages for a Proficient Piano Player to Complete a Piece: Focusing on the Interplay Between Conscious and Unconscious Processes.** *International Journal on Advances in Life Sciences*, 16:164–177, 2024.