PHIL 3422 Spring 2016
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2016-05-26

The flow experience as the phenomenological aspect of a cognitive theory of attention

Abstract

In this essay we present an argument that the subjective experience of flow is the phenomenological aspect of a cognitive process that maximizes Shannon entropy of information transmission. This process provides a substantial enough channel for pertinent information to facilitate the operant task at hand, while minimizing the overall channel size of all information. As the information requirements of a task change dynamically, so does the channel size that this process provides. In folk psychology terms this would be known as 'attention'.

We hypothesize that this function in the mind has evolved as our environmentally driven need to process ever increasing amounts of information has been constricted by the biological limitations presented by our physical brain structure. Activities such as assimilating rules of a task, predicting or imagining future outcomes, and simulating the thoughts of others are all “full duplex” in that they require both accessing a cognitive model of a task and updating it simultaneously. As this complex process requires an order of magnitude more information transmission than the relatively simpler process of sensory input, the entropy of the signal has a magnified impact on the effectiveness of the activity. A highly effective means to increase entropy of a signal is to restrict the domain of possible symbols that can be represented to as closely match the actual set of symbols encountered, and to formulate a structure of symbol probabilities to allow more frequent symbols to be represented in less space. If we can consider the mind to be an information processing machine, it follows that such a mechanism may have evolved.

We hypothesize that the subjective experiences of flow: intense and focused concentration, merging of action and awareness, loss of reflective self-consciousness, heightened sense of control, and distortion of temporal experience can all be explained by such a process occurring. When presented with a task that has a sufficient level of complexity, our minds attempt to create a model of the task that allows us to predict outcomes of various decisions to allow us to maximize our performance of the task. With repeated exposure to the task, both the accuracy of the predictions and the understanding of sensory pertinence increases. Our mind builds a probability map of symbol pertinence for each task we undertake. As these maps approach states of completion, the source coding of the mind's internal information transmission adapts to maximize entropy by restricting the domain of symbols to only those present in the task's probability map. We argue that the subjective experiences of focused attention, merging of action and awareness, and sense of control are directly related to the restricted source domain that is active at any given moment.

Consistent with the modular theory of mind, a sufficiently formed task-specific prediction model and symbol probability map can combine into a task-specific execution unit that operates on a similar level of the theorized executive control unit. We are trained through classical conditioning to enter into a state where the appropriate task-specific execution unit assumes control of action output and receives input directly from sensory units. As a means of mediating this transfer of control, a set of task-specific cues that are present before a task commences acts as a conditioning stimulus that guides our mind through the hierarchy of task models to select the appropriate one to hand control to. The reward in this system would be linked to how well the predictions of outcomes of our decisions driven by the task model coincides with the actual outcomes. We hypothesize that a sufficient perceived match between prediction and outcome releases endorphins which act to both reinforce the conditioning stimulus and to further train the model and prune the symbol probability tree. This mechanism is responsible for the sense of euphoria felt by many people when subject to the flow state.

Finally, We present several potential experiments which could falsify or verify the hypotheses presented. One set of experiments focuses on determining whether unrelated uses of a specific cognitive unit are synergistic or antagonistic, and the other focuses on determining whether the categorization of flow state into challenge vs. experience based phenomenon is justified, or if we can form a unified model of the two.

Introduction and Motivation

Many efforts to develop a cognitive framework of the mind focus on disorders of the mind, either developmental or acquired as an adult. In either of these situations the functional differences used to develop the models are highly subjective due to individual differences between the nature of the disorders, as each particular case of developmental or adult disorder is unique to that individual. It is also not clear whether results determined through study of subjects with cognitive disorders can be presumed to also apply to the population as a whole. If instead we consider investigating a phenomenon which is considered a normal everyday occurrence among healthy subjects, we may be able to develop a model which is not encumbered by the controversy surrounding the use of cognitive disorders among small sub-sets of the population to identify discrete components of a classical architecture of mind.

The flow state is the holistic sensation that is experienced when performing a task with fully focused attention. We propose using the flow state experience, the subjective experience of which has been studied extensively and has a body of empirical findings. Also we hypothesize that the flow state experience is the phenomenological side effect of information chunking, and has developed through evolutionary pressure to promote adaptability to various disparate environments with wildly different tasks. A laboratory experiment is proposed to ascertain whether task unrelated activation of proposed cognitive units has a synergistic, antagonistic, or no effect on subsequent task related activation.

Further, in prior flow experience research inconsistencies arise in the link between skill/challenge balance of a task and subsequent flow experience. We propose that a fundamental misunderstanding of the structure of tasks may be involved, and propose a categorization of tasks that alleviates this inconsistency. A field experiment utilizing ubiquitous computing devices is proposed to ascertain what has a larger impact on the flow state: the skills-challenge balance of a subject / task, or the subject learning of progressively higher levels of a task's logic. The outcome of such an experiment may provide a basis to remove the categorization of flow inducing tasks based on performance vs experience.

The architecture of information chunking

A 'chunk' is a collection of symbol elements which have strong associations amongst each other, and weak associations with elements of other chunks (Herbert A. Simon, 1974). Chunks are theorized to reside in the Long-Term Memory (LTM) and are accessible to cognitive processes that occur in Short-Term Memory (STM) through 'pointers' which occupy far less space than the contents of the chunks would occupy, thus allowing more working memory to be stored in STM.

Gobet investigated several computational models of information 'chunking' applied to various domains and found a significant enough overlap to suggest that a common mechanism of chunking underlies many aspects of learning (Gobet et al., 2001). The Elementary Perceiver and Memorizer (EPAM) and subsequent derivative Chunk Hierarchy and Retrieval Structure (CHREST) are two such architectures that provide adaptable, self-organizing frameworks for studying the role of chunking in various tasks.

According to Gobet, there are two major categories of chunking: *goal-oriented chunking*, and *perceptual chunking*. The first type can be described as a *conscious, intentional* process, in which an individual analyzes input features for some pattern which can be used as a heuristic for future recall during related tasks. The second type can be described as an *unconscious, automatic* process, in which an individual is not aware of the functional role being performed by the chunking database nor the pattern or structure of features that key to that particular chunk. Though automatic motor-skills learning has been demonstrated to be independent of conscious memory (Corkin, 1968), there is no conclusive evidence suggesting that goal-oriented and perceptual chunking are either independent or linked processes. In either case, learning involves a process of searching the existing chunk database for a set of features, and if no prior chunk exists, creating a new entry in the chunk database. If a sub-set of perceived features is linked to a prior chunk in the database, an analysis is performed to determine if additional perceived features in the input set warrant creation of a new, higher-level chunk to supplement or replace the existing chunk. In this way a 'search tree' structure is formed, allowing efficient search and retrieval of chunk pointers in a vastly more efficient way than would be realized under a flat organizational structure (Schmidt & Lipson, 2007).

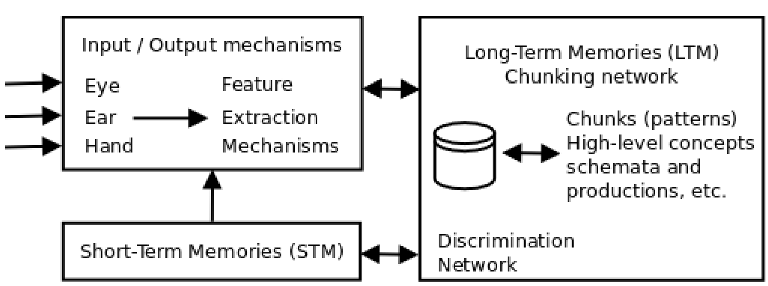

Figure 1: EPAM/CHREST architecture. Adapted from Gobet 2001.

Finitely vs Infinitely complex tasks and Medium vs Message

We can consider two categories of tasks: those that have a finite set of unambiguously perceptible symbols, rules, and outcomes; and those that do not. Of the former, we can presume that an individual learning the task may reach a point where they have successfully encoded all of the symbols/rules that pertain to the task, and therefore have a complete database of these symbols available to a task-specific execution unit. For this particular individual performing this particular task, we can assume that subsequent performance of this task will not involve conscious processing to retrieve the meanings of these basic symbols, and that any further information assimilation would relate to the next higher level in the hierarchy of the task's “meta-task” structure. To be able to speak clearly about this distinction, I propose the terms *medium* and *message*. The message encompasses the intrinsic properties of the task: the set of symbols, rules, and outcomes that conceptually define the task. The medium includes all of the elements that are dependent upon a particular instance of the task. This may include such factors as the properties of other people involved in the task, the environmental situation in which the task is being performed, and anything else that is external to the intrinsic properties of the task. In the case of a game with a fixed set of rules and clearly defined conditions for outcomes, we can say that the message incorporates the set of rules and outcomes that define what it mean for anyone to 'play' the game, and the medium would be the environment in which the game is being played. For example, playing chess on a lazy saturday afternoon with a child is an entirely different experience to playing chess in a tournament against a grandmaster, or attempting to play chess while skydiving. Even though the rules and outcomes of the game are the same in all cases, the challenges presented are different.

Example: Expertise in Chess

It is common to focus on learning the strategy of playing chess only after internalizing the basic rules of the game including piece movements, check conditions, etc. Since there are a finite number of such rules, with sufficiently experience the player will reach a point of having the basic rules fully internalized. At this point it may be the case that the IAU unit has provided sufficient complexity to form a “chess rule” execution unit. Subsequently, the novice player no longer has to consciously recall basic chess rules to evaluate potential rules, unless a previously unknown rule is encountered such as *en passant*. If such a novice player then only plays opponents at this same development level, no further new learning takes place and the game becomes a rote mechanical exchange: this can lead to the 'boredom' state in the flow theory. On the other hand, a novice player faced with the challenge of a more skilled opponent and a desire to learn to play better will begin to develop a set of symbols that function at a higher level of play strategy than what they have already learned. With enough experience against such 'challenging opponents', a player can develop the ability to automatically perceptually recognize the state of the entire board as discrete symbols instead of as ensembles of piece symbols. She can then focus on learning valid board states instead of continually consciously assembling piece level rules to form a model of the current board state.

Expert players have a much greater performance in short-term recall tasks of valid chess board states than novices, whereas experts and novices ability to recall random chess board states were about equal (De Groot, 1965). Also, expert players focus more on the outcomes of 'good' moves, whereas novice players focus equally on the outcomes of both 'good' and 'bad' moves (H. A. Simon & Chase, 1973). This implies that expert players have internalized a set of symbols which form a database of valid chess board states, and which excludes non-valid states. Since the set of all valid game boards has a much lower cardinality than the set of all possible random board states, the size of a unique key to a database containing valid states would require much less storage space than the equivalent ensemble of piece-level states (Feigenbaum & Simon, 1984; Gobet et al., 2001). Since humans have limited short term memory (Cowan, 2008), It is reasonable to argue that having a more space-efficient set of symbols to represent a task allows a player to perform better at that task, as they would be able to simultaneously compare more states of the task, or perform more simulations of future task states, and also to generate a 'fitness' heuristic, I.e. automatically categorizing 'good' from 'bad' moves without having to access all of the specific move implications or consequences in STM. Expert chess players don't have a radically different methodology than novices in determining the next move to make, instead they are better at subconsciously picking which moves to not consider at all (Chase & Simon, 1973; De Groot, 1965). This leads credence to the notion that they have formed an efficient method to 'prune' the prediction space of sub-optimal choices, and that this happens at an automatic level triggered directly from the perception module. It is thus necessary for some process to occur which transforms a chunk from being accessible only to the intentional mind into one accessible to the automatic mind. I propose that this process results in the phenomenology of the flow experience.

Evolutionary basis for chunking: Enjoyment

In the case where performing complex tasks is critical for an individual to survive to a point where they can produce and nurture offspring, evolutionary natural selection has shaped our minds to seek out more efficient sets of symbols to represent the tasks that we routinely engage in. This sort of heuristic process having an evolutionary basis is a widely held theory in the field of cognitive science (Cosmides & Tooby, 1994). To the extent that rewarding outcomes reinforce behaviors, we can hypothesize it is evolutionarily advantageous to have a mechanism by which successful assimilation of domain knowledge into successively more efficient symbols produces a rewarding outcome. Csikszentmihalyi refers to this as 'enjoyment,' in contrast to 'pleasure':

> *"Enjoyment, on the other hand, is not always pleasant, and it can be very stressful at times. A mountain climber, for example, may be close to freezing, utterly exhausted, and in danger of falling into a bottomless crevasse, yet he wouldn't want to be anywhere else. Sipping a piña colada under a palm tree at the edge of the turquoise ocean is idyllic, but it just doesn't compare to the exhilaration he feels on the windswept ridge"* - *(2003)*

It has been shown that language acquisition, a task which is challenging and not intrinsically pleasant, activates reward systems in the brain and motivates further word-learning (Haber & Knutson, 2009; Ripoll??s et al., 2014; Syal & Finlay, 2011). On a neurological level, these rewards are induced by release of neurotransmitters called endorphins. I propose that this reward mechanism is not merely linked to language acquisition, but at a more fundamental level to the successful encoding of novel symbolic information into chunks in the CHREST database mentioned earlier. Chimpanzees and humans share a similar reward circuit (Haber & Knutson, 2009) though there is no indication that they intrinsically learn words without human influence. Chimpanzees do however exhibit performance on tasks that may involve an information chunking process. (Boysen & Berntson, 1989), (Conway & Christiansen, 2001).

Autotelic activities

Autotelic activities are intrinsically motivated, goal-directed activities that require significant physical or mental effort on the part of the actors (Csikszentmihalyi, 1975). Common amongst all such activities is the presence of relatively difficult challenges that are not quite beyond the perceived capabilities of the participant (Sami Abuhamdeh & Csikszentmihalyi, 2012). When viewed from this perspective, prior studies have discounted the notion that "passive" activities such as watching television can be autotelic (S. Abuhamdeh & Csikszentmihalyi, 2012; Csikszentmihalyi, 1975).

We propose that certain passive activities, such as watching an appropriate television show, sports match, or movie, can be an autotelic activity. The challenge presented is the ability to assimilate the information that is being presented in the show, to exercise empathic ability by simulating the mental state of the characters, or to deduce future outcomes of the plot or event. All of these activities utilize cognitive modules that are theorized to contribute to the sense of theory of mind, and that require mental effort on the part of the actor to both generate a model of another actor's mind, and to update it based on new incoming information. It is unlikely that a sophisticated adult who is used to watching crime dramas will find a child's educational show to be autotelic; In this case the characters and scenarios presented do not provide any challenges that are barely within the adult's perceived capabilities. Conversely, a child would not likely find watch a sophisticated crime drama to be autotelic (Gladwell, 2000). As long as the information presented in the show is at an equal conceptual level as the model that the watcher is building of the character's minds, continued assimilation of new information into the model occurs. Children's non-educational shows such as 'Spongebob squarepants' are designed to provide information that is at both a child and adult level, and thus can provide an autotelic experience for both. On the other hand, infant's educational programs such as 'Blue's clues' do not provide a dual level of information, and thus do not have an adult appeal.

We can also clearly see that sports fans have a high level of affective participation with and empathy for their team when spectating a match (Park, Ha, & Mahony, 2014; Wann, Friedman, McHale, & Jaffe, 2003). When a fan's team does well, there is a lasting positive effect on the fan's affective state. When the team does poorly, there is a lasting negative effect on the fan's affective state. From this we can speculate that as the fan watches the match, they are assimilating information into both a model of the player's minds as well as a predictive model of the game itself, with the phenomenological effect of the former being an empathetic mirroring of the player's perceived affective state, and of the latter being the flow state.

In the case of such passive activities the skills-challenge balance is achieved not through the medium of the activity, but through the message transmitted in the activity. In the case of those activities traditionally considered autotelic (mountain climbing, chess, surgery, basketball, etc) the message is typically fixed (the set of 'rules of the game' and/or set of outcome expectations) and the challenge is in elements of stochastic variability present in the medium (the particular mountain, the chess opponent, the surgical procedure and patient complications, etc). From this perspective we do not need to be concerned about theoretical complications that arise since both autotelic and non-autotelic activities can cause the flow state, as there are likely a autotelic activities hiding within the passive 'non-autotelic' activities that have been empirically shown to induce flow.

Flow from self-involved activity vs simulation of other's activity

Flow is not a single uniform experience – each sub-task can enter a state of exclusive execution, which phenomenologically manifests as the flow experience as the information channel unit shapes the incoming sensory information to suit each sub-task as it executes. The act of assimilating information – i.e. encoding an ensemble of temporally local perceptions into domain-specific symbols – itself is a task which can enter a self-directing feedback loop and thus induces the flow experience. In this way, an individual can experience flow during mere learning of a task. This state would not be activated by the same mechanics that would activate a similar state once the task is fully learned, but the conscious experience would consist of similar phenomenon.

For many activities, performance is reliant upon assimilation of the rules of the game (the message) only to a certain level. Above that level, progressive improvement is gained by assimilating instance specific information (the medium) and developing a means to efficiently search this instance specific database of sensory tokens without having to subsequently involve conscious effort. There are two types of such instance information that we will discuss: Other participant's behaviors that lead to development models of that are specific to each other participant's mind as it relates to performing the task, and environmental factors that can have an impact on outcomes of the task. We propose that the former utilizes the same cognitive modules that are involved with empathy and theory of mind, and the latter utilizes the same cognitive modules that are involved with locomotion and somatosense. We hypothesize that there are two possible scenarios relating to these mechanisms: 1) that there exists a single unified 'theory of mind' execution unit which can only operate to simulate one specific other mind at any one time, or 2) each model of an other's mind is a self-contained execution unit, and subsequently several different simulations of other's minds can be held simultaneously for use by a task.

Example: pre-game rituals in sports

In many cases a person may have several related activities in which they participate, but that have a different set of required actions based on similar sets of perceived conditions. For example, a basketball player would have several court-related activities:

1. Playing a competitive match
2. Participating in a 'faux' match amongst team-mates
3. Practicing drills
4. Coaching others
5. Leisurely playing non-competitively

Most environmental cues that are present leading up to the start of the task are common predictors to all of these tasks, and would not effectively work as conditioned stimuli to lead the mind into the right predictive task model. As the importance of the outcome of a task rises (with the most important being competitive matches) the need for a specific set of cues to act as a task selection stimulus rises. Pre-game rituals are widespread in all forms of competitive sport and have been shown to increase performance {Reformatting Citation}. We hypothesize that pre-game rituals[1] are subconsciously developed by players as a mechanism to guide their mind to selecting the correct task-specific performance module. Rituals such as high-fiving team-mates after free-throws, even if no team-mates are present[2], can be interpreted as acting like conditioned stimuli for entering the 'free throw' game sub-task. Conveniently absent in the sporting world are post-game, pre-practice, or pre-leisure play rituals. However, in some cases such as motorcycle sports, both competitive races and leisure riding have been shown to have pre-task rituals {Formatting Citation}. In this case it may be an example of a task that has a high level of importance of performance even in a leisure setting, as a failure to perform at a sufficient baseline level can lead to injury or death.

In the case of coaching others, We can speculate that a combination of the other's mind awareness, situational environment

1 See https://www.youtube.com/watch?v=NfI6qnEEUAc for a compilation of examples of this phenomenon, and See https://www.youtube.com/watch?v=ONCyV9Dd2v0 for an in-depth example.

2 See https://www.youtube.com/watch?v=bqP5TVxmD3Q for an example of this phenomenon.

awareness, and the rules of the task units will operate at a conscious level, as the task of coaching involves combining elements of all three types of information into a compact form which can be transmitted to the other participant efficiently, either through speech, or pantomime, or a performance exaggerating certain important elements of play. We hypothesize that coaching will not induce the flow experience, as part of the requirements of the activity is to maintain a broad range of attentional inputs, thus any specific sub-task unit would be prevented from inducing a feedback / flow state.

Potential laboratory experimental framework

In order to falsify or verify the claims made in this essay, it would be required to have means to empirically demonstrate the hypotheses to be either true or false. I propose the following set of tasks which can be combined in various ways in a laboratory setting:

1. Sense of mind challenge task – The card game 'I doubt it' by Hoyle, also known as 'Bologna' or 'Bullsh*t'. The game presents a simple set of rules which can be assimilated quickly or may be known already to the subjects. The complexity in the game lies in the ability to read other player's intentions and to mask your own intent. A game between subjects with no prior exposure to each other provides a context in which constructing a task-specific model of another person's mind is required to succeed.
2. Adverse sense of mind task – Subjects are asked to think about a person that is important in their life, and to imagine that person's reaction to a hypothetical difficult situation presented on a slide. Subjects are asked to describe how they would feel and what they would perceive as if they were that person in the situation presented.
3. Symbols assimilation challenge task – The card game 'French slap' also known as 'Egyptian War'. In this game, players must recognize that certain defined sequences of cards are played to win each round. The symbols to be encoded are not the specific values of cards, but the rules of the sequences that must be acted upon. As a wide variety of sequences can be defined as the play criteria, a rich set of adverse prediction models can be developed by the players.
4. Adverse assimilation task – This could simply be the same card game but with a different sequence criteria.
5. Symbol identification task – Subjects are presented with slides containing several sets of numbers and asked to identify sequences that are present in some of the sets.
6. Stochastic prediction task – The card game 'War' which requires no choices by the players and the outcomes of which are determined solely by the order of the cards. When played with several players and a small deck, it presents the opportunity to 'count cards' and build a prediction model specific to that deck order.
7. Adverse prediction task – Subjects are shown a series of slides with three panels of a four panel cartoon and asked to describe how they imagine what the fourth panel would contain.
8. Coaching task – Subjects are asked to teach a confederate who feigns ignorance of the task how to perform the task which had been learned earlier in the session.

An experiment could combine a challenge, its related adverse task, and then the challenge again in quick succession. Control conditions would either omit a task or replace it with a non-related task. Measurements would include rate of performance increase, response times, quality and quantity of descriptions in adverse tasks, and self-reported enjoyment and flow questionnaires after the conclusion of the tasks. An emotional state questionnaire should be administered both before and after the session to account for the effect of any preexisting emotional states on task performance, and on the emotional effect of the task. An optimal strategy would involve a single subject per session playing against experimenter confederates, although it could be possible to have several subjects playing against each other if the data

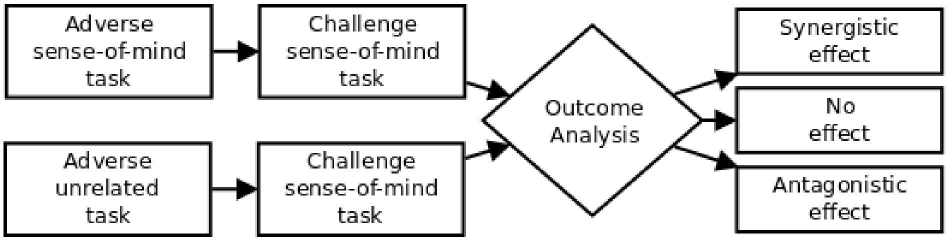

Figure 2: An experiment design to determine the effect of priming a challenge task

recording capability is sufficiently organized. If a synergistic effect is found, we propose that this indicates that the cognitive unit is inherently parallel, and priming with the unrelated action recalls the unit into working memory. If an antagonistic effect is found, we propose that this indicates that each task competes for the limited availability of the cognitive unit, and that this in turn may indicate that it is actually a composite unit with serial connections. If no effect is found then no conclusions can be ascertained.

To investigate the effect of coaching on flow experience, the following experimental scenario could be undertaken:

1. In the induction, the subject is told by a confederate of the experimenter that they (the confederate) is the previous session's subject, and that they were tasked with teaching the rules of the game and social strategies (eg. cheating, detecting cheating in the sense of mind challenge task) to the next subject (the subject) prior to playing, and that they (the subject) will be responsible to teach the next subject.
2. The confederate teaches the game to the subject while they are playing with two other confederates or subjects, as the game requires at least four players for the social aspects to emerge in play. While teaching, the confederate continually reminds the subject that they will be expected to teach the next subject.
3. Play continues for several rounds with no teaching. At the conclusion the subject is asked to complete a flow experience questionnaire, and informed that they won't actually be required to teach the next subject.

We hypothesize that given a task (coaching a future unknown person) that requires conscious utilization of the empathy cognitive unit and conscious analysis of environmental stimuli, those participants subjected to the coaching scenario would have a drastically reduced occurrence of flow experience compared to those that were not asked to coach.

Potential field experiment with ubiquitous computing framework

These days almost everyone has a smartphone, and subsequently their use as a platform for performing behavior experimentation is compelling. By developing an app that can run on subjects' phones, experiments can be conducted on a large scale without having to utilize a traditional laboratory setting {Formatting Citation}. Data collection can be as fine-grained as required for the test, and a summary of the data collected can even be presented to the subject after the conclusion of the experiment. Cloud based storage and analytics can provide an inexpensive and scalable platform to allow such experiments to achieve high levels of correlational confidence and provide a means to dynamically adapt the experiment parameters as new hypothesis are considered {Formatting Citation}.

In particular, it has been demonstrated that levels of stress and interest in a task can be reliably measured using an analysis of touch-screen swipe gestures {Formatting Citation}. By restricting the output to four discrete states: *Anxiety*, *Boredom*, *Apathy*, and *Interest*, Gao was able to achieve an >80% reliability of sentiment analysis using only the length, speed, and pressure of swipes. This leaves the fourth dimension of direction available for a task-related use. The popular game *2048* involves a simple user interface in which the only dimension of input required is direction, thus being suitable for use in such an experiment that requires the other dimensions to be fully involved with the sentiment analysis. *2048* also presents a hierarchy of strategies that must be successively discovered by a player to be able to progress in score beyond score plateaus. By introducing a dynamic adjustment of the game engine based on immediate feedback of the user's detected sentiment and level of performance, we can provide an environment in which we can actively maintain a skill / challenge balance. Also, by analyzing the subject's performance for strategy level indicators, we can provide a means to shape the game environment to maximize the subject's ability to learn new strategies and continue to assimilate novel information into a cognitive model of the task. By carefully mediating the game engine's deviation from standard behavior, we can manipulate the subject's perception of fairness of the game environment.

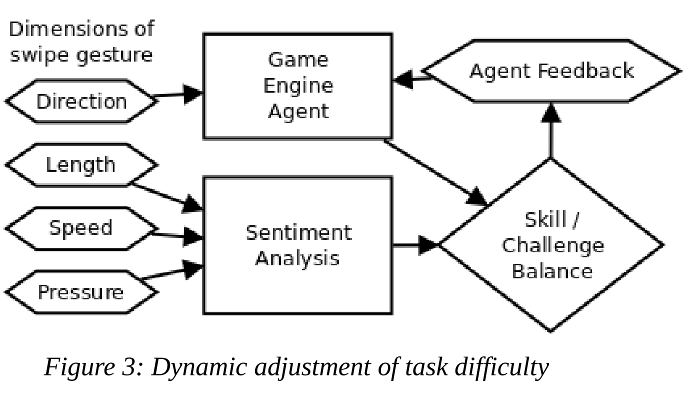

Figure 3: Dynamic adjustment of task difficulty

With a combination of these mechanisms, we can attempt to answer the question: 'Is it the skills / challenge balance or the assimilation of task-relevant information that induces and perpetuates the flow state?' and 'Does a perception of fairness or unfairness play a role in flow state?'

We propose the following 'Agents' that would modify the *2048* game environment by 'loading the dice' and altering the stochastic element of the game in such a way as to induce the desired effect:

1. Standard Agent – after each move, a cell is chosen at random uniformly from the set of all open cells, and populated with a uniformly random value from the set of valid initial cells. This is analogous to the standard, unmodified behavior of the game.
2. Angel Agent – after each move, a cell is chosen at random, biased toward cells that would provide the most benefit to the player, and populated with a value from the set of valid initial cells that would benefit the player.
3. Challenge Agent – after each move, a cell is chosen at random, biased towards cells that would provide the least benefit or detrimental to the player, and populated with a value from the set of valid initial cells that would hurt the player.
4. Teacher Agent – after each move, a cell is chosen that maximizes the probability that the user will enter a game state that is characteristic of the next higher level of strategic play than they are currently playing. To intentionally appear either covert or overt, this behavior would be co-mingled with standard agent behavior at a ratio determined by analysis of the player's performance and sentiment, modified by the parameters of the particular experiment.
5. Cheater Agent – after each move, a cell is chosen at random or specifically that maximizes the detriment to the player. Like the Teacher agent, the level of covert / overtness can be controlled based on the parameters of the particular experiment.

By randomly selecting participants to have various agents active during their sessions, we can attempt to build a correlational model of what factors impact the initiation and sustenance of the flow state experience. This could help to develop a model of the flow state that unifies the concepts of experiential and performance based flow. We could also determine if an intuitive sense of fairness contributes to the flow experience: Would a player's awareness that the game is rigged impact their ability to experience flow?

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