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Implementation of Conservation Operationalisation

Bachelor's Project Thesis

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Abstract: Conservation is the understanding, that, although the dimensions of a given object can change, the mass or quantity of that object remains constant. This concept of conservation is very difficult for young children yet feels intuitive to adults. Many studies have focused on when conservation starts, but little has been done to identify how the understanding of conservation develops or how children move through the various conservation strategies. This paper focuses on generating an ACT-R (Adaptive Control of Thought - Rational) model that replicates previous studies on conservation by implementing an operationalised theoretical model by Siegler (Siegler, 1981). Results show that an operationalised model has to be more complex than previously thought to fully replicate the development of conservation strategies.

Keywords: ACT-R, child development, cognition, conservation, prospective memory

1 Introduction

Imagine two glasses of water in front of you, glass A and glass B. Both are identical, the same size with the same volume of water inside. The contents of glass B are poured into glasses C and D. Which has more water; glass A or glasses C and D combined? This isn't a trick question, glass A has the same volume of water as the combined glasses C and D. The answer may seem obvious, even trivial, yet this is a question young children easily get wrong. Some children will believe that A has more because the water level is higher or that A has less because there is only one glass of water (Piaget, 1965, p.6-7). Somehow, children are able to develop from a state of no understanding, to a state of disbelief that it is possible to get the answer wrong. The ability to conserve has been studied for years without fully researching into how children conserve.

The research into conservation began with Piaget and his work with child development and the publication of his book The Child's Conception of Number (Piaget, 1965). He theorised that children between the age of four and eleven develop the ability to judge the quantity of multiple objects in comparison to one another (Piaget, 1965, p.9). Conservation is the ability to understand, regardless if the dimensions of an object change, that the physical quantity of an object remains constant. It develops during the preoperational and concrete stages of child development.

In Piaget's (1965, p.4) studies, the experimenter would show the child two identical objects. The child would confirm that these two objects are equal before the experimenter performs a transformation to one or both of the objects. This transformation could make one of the objects smaller, larger, or only change dimensions of the object. The child would be asked if the two objects are equal again. If the child says the right answer, it is given that this child is able to conserve. There are multiple variations of the conservation task using different mediums (Ginsburg and Opper, 1988, p.175). The three focused on in this research are number, solid, and liquid conservation tasks.

For tasks relating to number conservation, the experimenter placed two rows of marbles in front of the child. After the child had confirmed that the rows had the same number of marbles the experimenter would perform the transformation on one or both rows of marbles. The child was then asked if both lines were equal. The ability to perform number conservation is developed first, according to Piaget, around the age of four. Siegler (1981, p.51) believed that children used counting to solve number conservation problems before understanding that it wasn't necessary due to the quantity of the object not being changed. Other researchers believe that quantifying the objects is a separate development stage from which conservation develops (Klahr and Wallace, 1973; Bucher and Schneider, 1973).

With solid conservation the experimenter would produce two pieces of clay which were rolled out to be equal length. Once the child had considered both the lengths to be equal the experimenter will perform the transformation on one or both lines of clay. The results from Siegler's research showed that solid and liquid develop at a similar rate with children beginning to develop the ability to conserve solids and liquids around the age of nine (Siegler, 1981, p.40-43).

For liquid conservation in Piaget's research, the experimenter would place two glasses of water in front of the child. Once the child confirmed they were equal, one of the glasses of water would be poured into another glass. This other glass would have different dimensions to the original. The child would, subsequently, be asked again if the water in each of the glasses was equal. This type of conservation is more difficult as the child would have to consider the three dimensions (height, width, and depth) to calculate if the two glasses contain equal volumes of water. In many experiments the glasses were cylindrical so were considered as two dimensional, the same consideration was applied to the cylindrical pieces of clay of solid conservation (Siegler, 1981).

The age at which children begin to develop conservation abilities varies. Some papers have found success with number conservation at the age of seven and that children under the age of five cannot perform conservation Bucher and Schneider (1973). Others have found successful conservation of number at a young age (Wohlwill and Lowe, 1962; Piaget, 1965). Gelman (1969) found that even if a child reported the right answer, their explanation of their answer showed little understanding of the problem presented to them. Studies that focused on the quantity of objects during number conservation found that when the number of objects increased, the age at which a child could conserve also increased (Klahr and Wallace, 1973). The youngest possible outcome being two or three objects with the child being aged between two and three years old (Klahr and Wallace, 1973, p.309).

Another reason that children are better as number conservation than solid or liquid conservation could be due to the knower-level theory (Lee and Sarnecka, 2010). The knower-level theory states that while children learn the meaning of the first few numbers, the rest are learned inductively through the assumption that the pattern of increasing value will continue. Children normally learn the meanings of "one", "two" and "three" before being able to assume the rest of the numbers. A study by Lee and Sarnecka (2010) showed that children between the ages of two and four were able to understand the value of small numbers though bringing a specified number of toys to the examiner and could be successfully modelled in terms of probability. This study sheds light on how childrens' understanding on number values and how they correlate to their respective number words.

Piaget split the initial development of conservation into three stages: Absence of conservation, intermediary reactions, and necessary conservation (Piaget, 1965, p.vii). While the child is unable to conserve (Stage I) they will use other methods of reasoning to justify a change in the quantity. For example, in liquid conservation a child was shown two glasses with equal volumes of water. One of the glasses of water was poured into two more glasses. When asked who had more water (himself with one glass, or his friend with two) the child responded that his friend had more water because they had two glasses and he only had one (Piaget, 1965, p.6). On the other hand, a child was given the same experiment and said that their friend had less because the water level was lower (Piaget, 1965, p.6).

During intermediate stage (Stage II) children begin the early stages of trying to perform conservation correctly. This involves the child thinking about more than one dimension of each object at the same time (Piaget, 1965, p.15). The second dimension is only considered if the initial dimensions of the objects are the same. For example, during Stage I a child may only take the height of a glass of water into consideration whereas in Stage II the child will also take the width of the glass into consideration with the height. The width of the glass is only taken into consideration if the heights of the water are the same.

The final stage of necessary conservation (Stage III) children are able to say immediately whether two objects are equal in quantity. At this point the child understands that even if the dimensions of an object change, the quantity of the object remains constant (Piaget, 1965, p.17).

For number conservation, the dominant dimension is considered to be the length of the row and the subordinate dimension is the density of the objects in the row. For mass and liquid the length of the clay and the height of the liquid are considered to be the dominant dimensions respectively. Since both mass and liquid could be considered to have more than one subordinate dimension, a "cross-sectional area" of the object is taken as the subordinate dimension (Siegler, 1981, p.8).

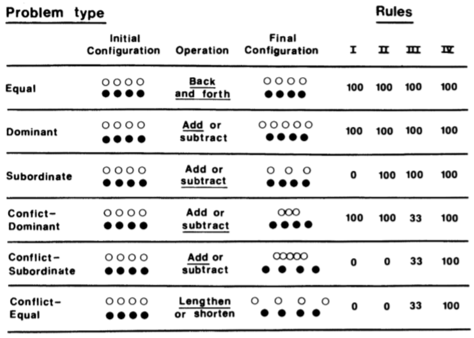


Figure 1.1: Figure 8 taken from Siegler (1981) showing the six different problem types for number conservation and the percentage chance of getting the answer correct.

The research performed after Piaget's initial publication focused on improving a child's ability to conserve through training (Bucher and Schneider, 1973; Paas, 1992) or though giving different conservation tasks (Gottfried, 1969). In the case of Bucher and Schneider (1973), they found that a child who was trained on conservation strategies performed better at number conservation than those who weren't trained on conservation strategies. Gottfried (1969) found that a child's ability to perform one conservation task positively correlates to their ability to perform another conservation task. This lead him to conclude that there must be some kind of skill transfer between the two. Piaget had previously believed that all conservation stages use the same mental operations (Siegler, 1981, p.2).

The majority of the research into conservation has focused on what age children are capable of using conservation and which strategies they use. Few researchers have focused on how children are capable of comparison of objects and understanding quantity. Based on Piaget's original stages, Siegler (2010) developed these into operationalised rules. Siegler created several problem types (Figure 1.1) based on the dimensional changes that are possible on a pair of objects (Siegler, 1981, p.10). The predictive outcome of each rule and problem was calculated according to what aspect of conservation development was being challenged. For example, a child using Rule I (which focused on the dominant dimension) would get the answer wrong if they were given a problem where only the subordinate dimension was changed.

Another, smaller, branch of conservation research was surrounding a child's ability to reason about their decision. Gelman (1969) found that a child's reasoning level was below their apparent conserving level and although the child gave the right answer, they couldn't fully explain it. Gelman explains one possibility is that the children do not have the verbal capacity to express what they mean. Piaget wrote that a child can understand conservation at the age of seven because, at that age, they can verbally communicate their understanding yet other researchers have claimed that younger children are capable of conservation even without being able to verbally articulate their answer (Siegler, 1981, p.33).

Piaget stages can be equated to Siegler's rules as followed: Rule I is equivalent to Stage I and only considers the dominant dimension of the object. If the dominant dimensions of both object are equal, then the objects themselves are equal. If the dominant dimensions aren't equal, then the greater dominant value is the larger object. Rules II and III correspond to Stage II. For Rules II and III, if the dominant dimensions are equal, the subordinate dimension is then considered. The calculation is again based on if the dimensions are equal. The difference in calculation occurs when the dominant dimensions aren't equal; for Rule II the object with greater dimension is seen to be the larger object, whereas Rule III uses the subordinate dimension. If both the dominant and subordinate dimensions of both objects are not equal, Rule III requires the child to "muddle through" to find the solution (Siegler, 1981, p.6). Rule IV is the final rule where the child is able to realise that the dimensions of the object aren't important but rather the transition that occurred. A child that is at Rule IV is able to conserve as they have realised that, even if the dimensions of the object have changed, the quantity of the object remains the same.

Siegler did four experiments to help verify his operationalised model of conservation. For this research the focus is on the results of Experiment Three. Experiment Three focuses on liquid, solid, and number conservation with children aged between three and nine years old. The experiment followed the traditional Piagetian style of object presentation. The six problem types were shown to the child in a random order a maximum of four times. The results showed that the majority of children used the rule based strategy. From the results it was possible to see that, during liquid conservation, the children mainly used Rule I and Rule IV with only two children using Rules II and III. The results also showed that number conservation develops sooner and faster than liquid or solid conservation and follows a different development strategy by being more reliant on Rule III.

For my project, a cognitive model of three different conservation tasks (number, solid, and liquid) based upon Siegler's original operationalised model of conservation will be built. There is little research on how conservation develops as well as most of the research being based on theories of the transfer of conservation skills. The cognitive model will use the rule model and problem types mentioned to develop a model of conservation. The results of Experiment Three will be used as a comparison between the model and conservation development and will be discussed further in Section 2. The results of Experiment Three will act as the expected results of the model. The research question will be: "is it possible to build a model of conservation, based on Siegler's operationalised model and results, which can accurately represent conservation development?".

As discussed earlier, there are a lot of different answers as to when children begin to use conservation techniques and when children are able to perform it. The issue of age will be avoided by designing a cognitive model which will be described by its abilities to conserve rather than attempting to recreate a specific age range. I will also avoid the issue surrounding a child's ability to articulate a correct explanation to their answer by taking the model's output as its highest comprehension level.

2 Siegler's Experiment & Results

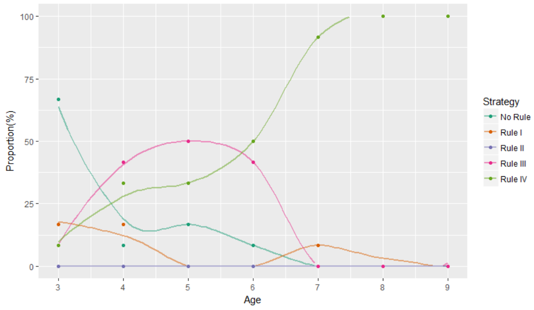
Siegler's theoretical model is based upon the results of several experiments performed in Developmental Sequences within and between Concepts (1981). The one that is focused on in this paper is Experiment Three (Siegler, 1981, p.33-?). The experiment focuses on the conservation of number, solid, and liquid with 84 participants divided evenly between the ages of three and nine. The conservation tasks were presented in Piagetian style.

For the number conservation task, the participants were shown two rows of coins of equal length and were asked if the two rows have the same number of coins after a transition had occurred. If the transition involved extending the row this was done in an exaggerated manner such as going from five inches to seven inches.

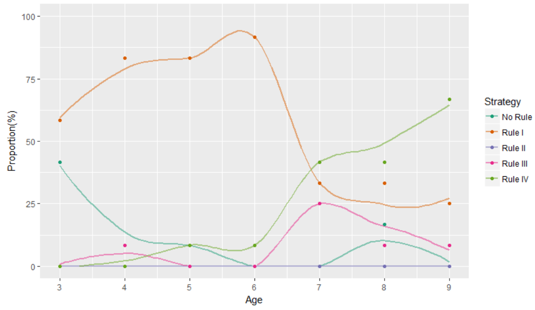
The participants were presented with two clay cylinders. The transition could involve the experimenter lengthening the cylinder from five inches to seven inches, the same as in number conservation. After the transition the participant was asked if the two pieces of clay have the same amount.

For liquid conservation the participant was shown two glasses of water, which were identical, as well as a third empty glass which would be used for the transition. The transition involved some or all of the water being poured into the empty glass; this glass could also be added to by another beaker of water that was present. The participants were asked if the new glass of water had the same amount as the old glass (one of the original identical glasses of water).

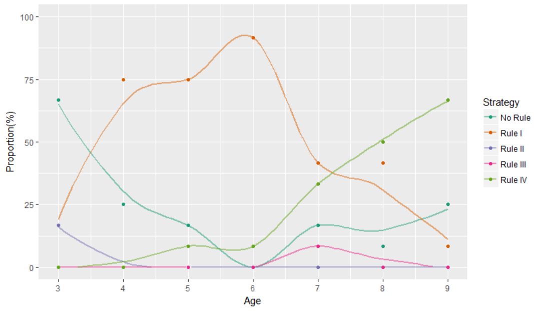
Each conservation task has six problem types (Figure 1.1). There is a total of four rounds leading to a total of 24 items shown. All six problem types are shown at random within each round. To gauge the response of the participants, they were asked to justify their answer. The participants often gave reasoning in terms of comparison to the other object (e.g. the second glass has a higher water level than the first) which helped the experimenter understand at which level they were reasoning. Since Rule IV relies on the understanding that physical



(a) Number Conservation



(b) Solid Conservation



(c) Liquid Conservation

Figure 2.1: A graphical form of the results in Table 7 (Siegler, 1981)

dimensions aren't required to solve the task, participants had to justify their answers in terms of the transformation (e.g. one coin has been removed from the row therefore there are fewer coins).

Number conservation was the only conservation type where the use of Rule III was in the majority for a period of time (Figure 2.1a). All other conservation types the participants mainly used Rule I and Rule IV with very few transitional strategies in between. All participants above the age of seven used Rule IV and were capable of explaining their answer in terms of transitions. Participants who used Rule I were solely reliant on the length of the row and did not consider the number of coins. The participants who used Rule III were considered to be a mix of Rule I and Rule IV where they would use different reasoning skills depending on the transition.

With solid conservation (Figure 2.1b) the majority of participants began with using No Rule strategies before quickly developing Rule I strategies. The participants tended to not use the transition Rules II and III and rather go straight from Rule I to Rule IV. All the participants who used a Rule I strategy used the length of the clay cylinder to calculate its mass. The participants who used Rule IV gave their answers in terms of transitions. In comparison to liquid conservation (Figure 2.1c), it appears that participants were faster at attaining the Rule IV strategy with solid conservation than with liquid.

According to Siegler's results, 67% of participants began liquid conservation using No Rule (Figure 2.1c). What is unusual, in comparison to number conservation, is that only two participants used Rule II and III as the majority of participants went from using Rule I to Rule IV without using any other rule stage. Siegler believed that this is because participants at the Rule I stage were beginning to understand that the cross-sectional area (volume) was important and went from only considering height to considering the glass of water as a whole. Participants using the Rule I strategy only looked at the height of the water while the majority using Rule IV used transitions. Even by the age of nine, some of the participants were still using No Rule compared to number conservation where 100% of the participants achieved Rule IV at the age of eight.

Participants who were capable of using Rule IV from an early age would apply transitioning explanations to all problem types they were shown, regardless of the conservation type. There were two participants who were capable of using Rule IV from a young age and did so on every task they were presented. Equally there was an older participant who used Rule I on every problem and conservation type.

Based on the idea that a participant can give one of three answers (equal, larger smaller) to each of the problem types (Figure 1.1), Rule I has a 50% chance of being correct, Rule II and Rule III have a 67% chance of being correct and Rule IV is correct 100% of the time. The additional No Rule, which is equivalent to guessing, is correct, on average, 33% of the time.

3 The Model

The operationalised conservation theory by Siegler was implemented by building a model in ACT-R, version 6. ACT-R (Adaptive Control of Thought - Rational) is a cognitive architecture capable of reproducing the results of human tasks (Anderson, 2007). The architecture is made up of two different types of memory: procedural and declarative. Knowledge stored in declarative memory (also known as chunks) can be accessed though procedural buffers which, in turn, are called upon in production rules. Production rules are loosely written "if then" statements which tell the model what to do with the given information. Although a later version of ACT-R is available (ACT-R version 7), ACT-R version 6 was used as it allows for the use of chunk slots with nil values (Bothell). This is used in the model to add previous unknown knowledge to a chunk without the need to create a new one.

3.1 Model Framework

The model starts by observing the objects pre- and post-transition. The dominant and subordinate values of each object in the post-transition position are stored. These are abstract values which are able to generate the answers required for each rule according to the problem type. In the final version of the model, the rule strategy is chosen based on the highest activity of a knowledge chunk in the declarative memory and whether the chunk generated the correct answer (Section 3.3). Earlier versions were based on which rule strategy would yield the highest reward (Section 3.2).

Each part of the rule strategy is an individual production rule in the model. Each sub-rule from the main rule strategy is its own production. For example, in Rule I the dominant dimensions being equal is a separate production rule to the dominant dimensions being bigger or smaller. When the model is comparing objects, the comparison is always done with respect to object one and the answer is always given in terms of object one. This is to make it easier when checking if the given answer is correct. The answers are stored in procedural memory, in a chunk, and are retrieved by searching for an index shared with the question chunk.

Rules I, II, and III use the dominant and subordinate to calculate the answer to the question whereas Rule IV uses quantity. Quantity represents the number of objects in number conservation and the generic size in solid and liquid conservation. Rule IV represents the child understanding the concept of conservation that, regardless of the dimensions, the mass of the object remains constant. With a dominant problem type (Figure 1.1) the object size is increased. In liquid conservation this would mean adding more water to the glass and in the model is represented by an increase in the quantity value. By comparing the quantity values the model will always get the answer correct.

If, at any point during a trial, the model cannot retrieve a piece of information (retrieval failure) the model will default to the No Rule strategy. This means that the model will always give an answer. The retrieval failure can act as a moment of forgetfulness in the model, similar to how it is difficult to get children to pay attention during experiments (Siegler, 1981; Bucher and Schneider, 1973; Gelman, 1969; Piaget, 1965).

As a child is supposed to use the same rule strategies for all conservation types, the rule strategies have been encoded in production rules in generalised terms. The model changes rule strategy when it deems necessary, rather than setting another rule to be available after a selected number of trials. This way the model's improvement is based on what it encounters and is a more flexible approach to modelling conservation tasks. It is possible to argue that certain aspects of conservation may not be available until children have reached a certain age, such as thinking in multiple dimensions, but as stated previously this paper is focused on modelling conservation development rather than age (van Rijn, van Someren, and van der Maas, 2003).

The model simulates multiple children performing several trials of the conservation task relating to number, solid and liquid. Each trial consists of the model simulating a Piagetian style conservation trial. The model is shown two objects and then a transition occurs according to Siegler's problem types. The visual buffer is not used in this model to fully replicate the transition, instead the model has a declarative memory of the objects pre- and post-transition. The model is capable of knowing how the objects were displayed before the transition, as well as knowing how they are currently displayed.

The model observes the objects then uses one of the rule strategies to calculate its answer. The answer is calculated by comparing the objects pre-transition to the objects post-transition. Once the answer is given the model is told if it was correct or incorrect and the process repeats for the given number of trials. The problem type for each trial is randomly generated. Multiple trials of the conservation tasks takes place in the same way as performed by Siegler in Section 2.

3.2 Utility Based Learning

Utility based learning is a reward based system where the model is rewarded based on actions it took to generate an answer. If the model gives a correct answer, that reward is propagated back through the actions (production rules) it took. This associates these production rules with better outcomes and makes the model more likely to choose those actions when given a new task. Rewards can also be negative to punish incorrect answers to make the relevant production rules less likely to be used by the model. The utility of each production rule is set before the model starts running.

The first iteration of the model was built using utility based learning. In utility learning, each rule strategy is given an initial utility which is then adjusted as the model runs according to getting an answer correct or incorrect. Initially the model has No Rule as the highest utility and Rule IV as the lowest utility. This means at the start of a trial, No Rule will be selected. After a few incorrect responses, the model will use Rule I. After several trials the model will use Rule IV and reach the optimal setting.

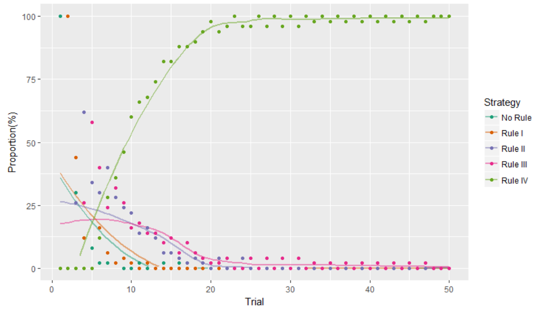
The model begins by looking at the object transition. After that the model chooses which rule strategy to apply based on the level of utility each rule has, the rule with the highest utility is selected. After the model calculates the answer, according to the rule strategy, it gives the answer. If the answer was correct the model is rewarded, an incorrect answer gets no reward. This is method is repeated for 50 trials and an average is calculated across 50 simulated participants shown in Figure 3.1.

Although number conservation (Figure 3.1a) reaches a success rate of 100%, it did not replicate the gradual progression where Rule III is used as a majority rule strategy. The model also fails to replicate the peak of Rule I in both solid and liquid conservation (Figures 3.1b and 3.1c respectively). The model fails to represent the gradual progression of rule strategy improvement which is displayed in Siegler's results in Figure 2.1.

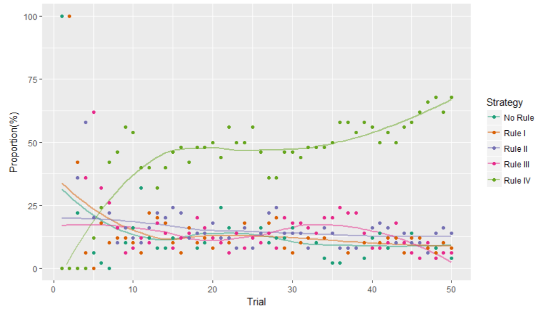
The model was built such that the same rule model could be used across all types of conservation. Although the model was able to achieve Rule IV, all types of conservation achieved the similar results and do not replicate Siegler's results. Siegler had documented that number conservation began with using No Rule, with the majority using Rule III at ages four and five with all participants reaching Rule IV by age seven. Solid and liquid conservation was different in that both peaked with Rule I. Most children used No Rule when they began solid conservation and Rule I when starting with liquid conservation. The model needs to reflect the different starting abilities of the participants and the strategies used in different conservation types rather than focusing on rewarding the correct strategy.

3.3 Instance Based Learning

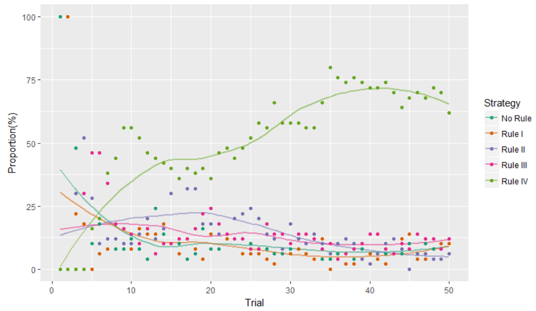
If utility based learning is about refining which strategy to use, instance based learning is about refining the knowledge about the situation. Instance based learning remembers what it has seen before and compares new situations to a previous similar memory. It is based on the activation of knowledge in the declarative memory. By using instance



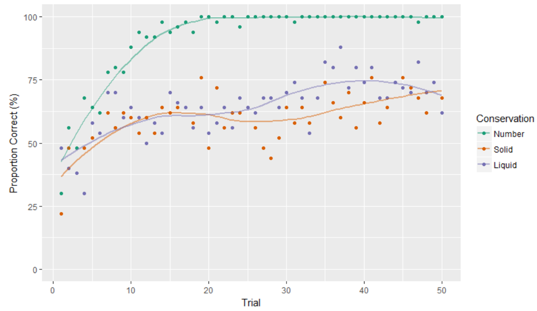
(a) Number Conservation



(b) Solid Conservation



(c) Liquid Conservation



(d) Model Correctness

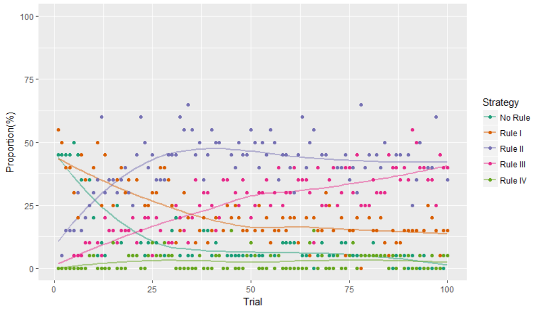
Figure 3.1: Utility Based Learning

based learning it is possible to adapt the stored information and make inferences about new situations based on previous experiences. The most recently accessed and strongest activated memories are stored. If a memory is accessed infrequently then there is a smaller chance of it being used and the chance of it being forgotten increases.

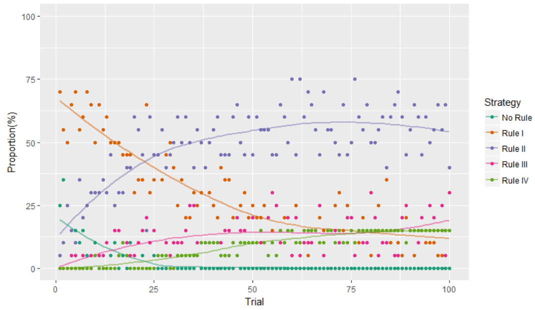
Instance based learning is based on activation of knowledge in the declarative memory. A fact that is more recently retrieved has more activation. Parameters such as "decay" and "fact similarity" can play a role in the successful retrieval of a fact. Using instance based learning, the model begins with chunks that represent the knowledge of each rule strategy. For example, when the model first starts with number conservation it believes that No Rule will give the correct answer. After a few trials it will realise that No Rule will generate incorrect answers and isn't the optimal strategy. At this point it will look for a different strategy to use. The model will remember that No Rule gave predominantly incorrect answers and will avoid using that strategy in favour of the new strategy.

If a strategy gives a false answer it will label that strategy as incorrect. This means all strategies, apart from Rule IV, will eventually be labelled as incorrect. The model is discouraged from using strategies that it knows are incorrect in favour of looking for a new strategy to use. The model will only retrieve rules that it knows to not be incorrect (the rule is correct or the model has no notion about the correctness of the rule). If there is a retrieval failure, the model has to use No Rule. For example, if the model knows that Rule II is incorrect, it will attempt to retrieve Rule III. If the model gets the answer incorrect it will again try to think of a better strategy with the assumption that this new strategy is correct.

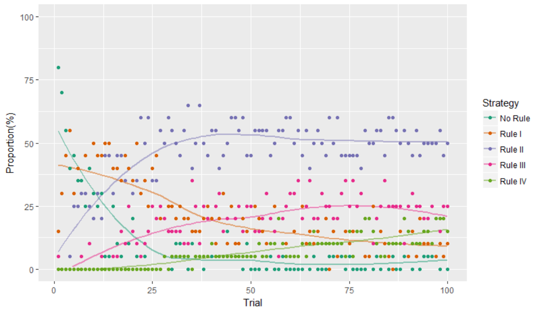
To ensure that the results resembled Siegler's data, the starting activation levels of the chunks were proportional to what responses the children gave. In solid conservation, Siegler showed that 42% and 58% of children began with rules No Rule and Rule I respectfully. The model began with the assumption that No Rule and Rule I generated correct results and the probability of the model choosing each rule was approximately 0.4 and 0.6 respectfully. For Rules II, III and IV the model had



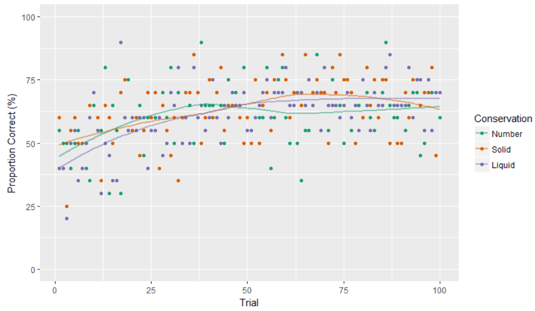
(a) Number Conservation



(b) Solid Conservation



(c) Liquid Conservation



(d) Model Correctness

Figure 3.2: Instance Based Learning

no knowledge about whether they would give a correct answer. The model ran 20 simulations with 100 trials each.

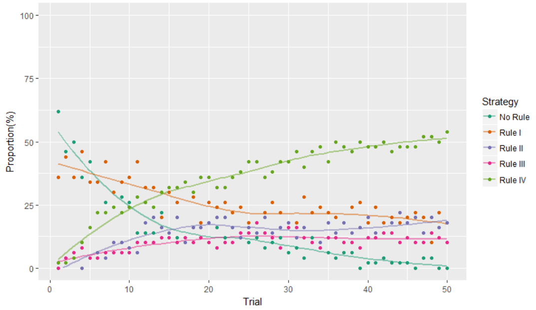
While the model begins with approximately the same proportion of participants using the same rule strategy as with Siegler's experiment, (Figure 3.2) the model soon reaches a plateau. The plateau is reached with Rule II in all types of conservation. The plateau is due to the probability of getting an answer correct with Rule II is only 67%. This rule is correct enough to keep the activation too high for the model to be able to use another rule strategy for any length of time. This results in a consistent use of Rule II and the plateau achieved in all types of conservation.

Although an instance based model showed a more gradual progression between the rule strategies, in comparison to utility based, it still lacked the later progression where Siegler's results show the use of Rules III and IV. A model that uses Rule II and gets the answer correct five times in a row isn't discouraged from using that rule if it gives one incorrect answer. The model needs to understand that an incorrect strategy isn't optimal and should search for a better strategy.

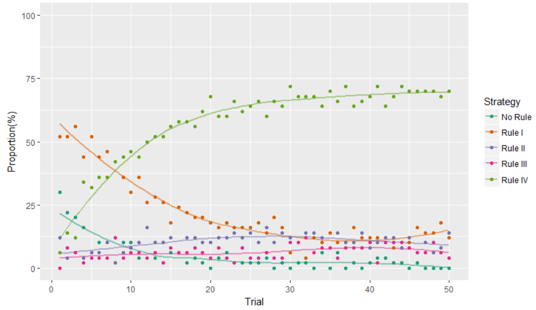
In a comparison of model correctness (how many answers the model got correct) utility based learning (Figure 3.1) performed better than instance based learning (Figure 3.2). This is partially because number conservation in utility based learning reached Rule IV while all other conservation types didn't. Model correctness should be improved as a large majority of children from Siegler's research achieved Rule IV and would get 100% of the conservation trials correct.

3.4 Prospective Memory Model

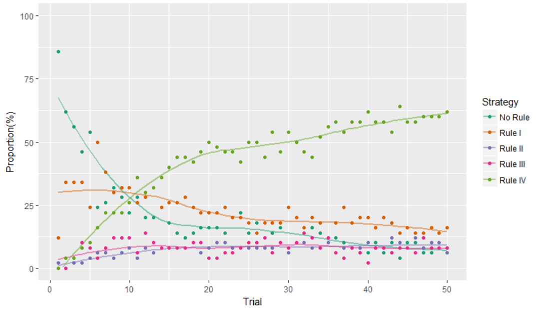
The model still needs further improvement to prevent the plateau at Rule II and to allow it to progress to Rule IV. This is achieved though a prospective memory strategy. prospective memory is an extension to the instanced based model which occurs after the model gets an answer incorrect. It allows the model to simulate going through the same trial again with a new rule strategy. After the model simulates the current trial with the new rule strategy it evaluates the output. If the model



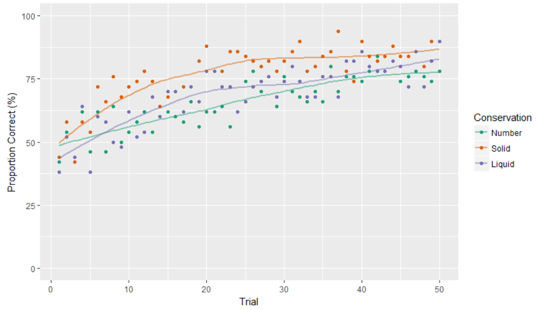
(a) Number Conservation



(b) Solid Conservation



(c) Liquid Conservation



(d) Model Correctness

Figure 3.3: Instance Based Learning with Prospective Memory

knows it would have got the answer correct with the new strategy, it reinforces this fact which gives the chunk a higher activation. If the model knows the answer would still be incorrect the chunk is still reinforced since this strategy is an improvement to the previous strategy. The model can only retrieve rule strategies that are an improvement on the previous strategy.

When the model gives a correct answer the answer is reinforced by trying to retrieve the knowledge chunk from declarative memory. If the fact already exists in memory it is reinforced. The reinforcement gives it a higher activation and makes the model more likely to choose that rule in the next trial. If the model was unable to retrieve that rule from memory because it has discovered this information and is therefore new. The model makes a new chunk in the declarative memory and stores this information with a high activation so it is more likely to be used in the next trial.

The model always retrieves a rule strategy that will give a better answer. A "better answer" can be defined as the rule strategy that is one level better. For example, an incorrect Rule I result will cause the model to try and retrieve Rule II or higher. The model will always retrieve knowledge of a higher power rule strategy but doesn't know what it would evaluate to. At this point the model will rehearse with the new strategy. This involves performing the conservation trial again with the new conservation strategy. The model performs the trial again to test the new strategy (a simulation of a simulation, if you will). Afterwards the model evaluates the result in comparison to the previous result. Both correct and incorrect responses are reinforced and stored in declarative chunks for the model to store later.

The model was ran with 20 simulations with 50 trials each (Figure 3.3). The model was able to reach Rule IV with all types of conservation. By allowing the model to study the choices it made and evaluate new strategies, it was able to improve upon the similar instance based method where the model plateaued at Rule III (Figure 3.2). Model correctness (Figure 3.3d) shows that solid and liquid conservation follow a similar pattern while number conservation correctness is slightly higher.

This is an improvement on the instance based model (Figure 3.2) as the model is able to reach

Rule IV which wasn't possible with using only instance based learning. This is also an improvement on the utility based model (Figure 3.1) as the prospective memory model allows a greater consideration of rules as well as generating answers based on previous experience.

3.5 Model Comparison

The final version of the model uses instance based learning and a prospective memory mechanism where the model can simulate how it could have performed differently using a better strategy. This model yielded the best results with regard to achieving Rule IV and using previous knowledge.

The clear difference between the model (Figure 3.3) and Siegler's results (Figure 2.1) is the use of Rule I. Siegler's data shows that Rule I was used heavily for solid and liquid conservation before using Rule IV whereas the model quickly disregards Rule I in favour of better performing rules. The model wants to achieve the best performance possible and Rule I is only 50% correct. Using a flexible approach to programming, where there is no restriction on when the model can achieve a rule strategy, it was difficult to get the model to consider Rule I beyond the point the model achieved an incorrect answer. The final proportion of simulations using Rule IV in the model is close to the proportion of children using Rule IV for solid and liquid conservation. Although the progress to achieve Rule IV was different, the model was still able to achieve the same conservation level as nine year old children in Siegler's experiment.

The development of number conservation by the model (Figure 3.3a) was very different to results that Siegler achieved (Figure 2.1a). The most notable difference being the use of Rule III. Siegler's data showed that children were highly reliant on Rule III between the ages of four and six before finally using Rule IV. All children were using Rule IV by the age of eight. In comparison, the model only achieved slightly over 50% of simulations using Rule IV after 50 trials. There is also no peak in the number of children using Rule III. The progression is slow and graduation from No Rule, Rule I, and finally Rule IV. A minority of simulations used Rule II and Rule III, this applies to all types of conservation the model simulated.

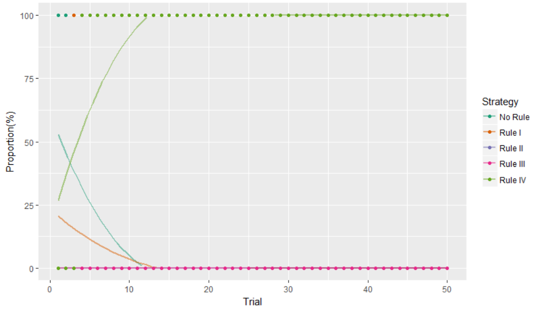
3.6 Individual Trials

There was a large variation in the simulations generated by the model. The most successful simulation was one which achieved Rule IV on the fourth trial (Figure 3.4a). The simulation got most of the answers to the previous trials incorrect while the least successful was one which had great success with the early strategies but failed to use Rule IV (Figure 3.4b). Every time the model got the answer incorrect it had to search for a better rule strategy. A simulation that always gets the answer incorrect would reach Rule IV by the fifth trial if it didn't just rule strategy stages. A simulation that was successful in the early trials with a more primitive rule strategy would have little motivation to change, due to high activation, and would remain with a sub-optimal rule strategy.

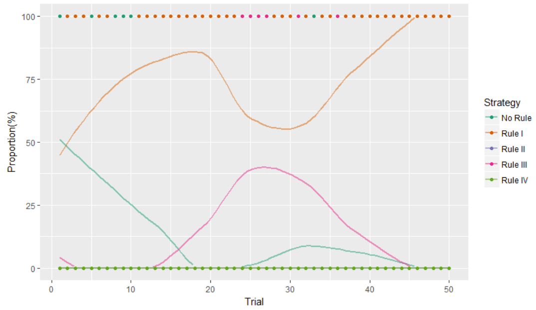
Similar to Siegler's research, just as not all children could conserve, not all the model simulations reached Rule IV. Figure 3.4b is an example of a simulation that didn't achieve beyond Rule III. This simulation was able to get the answer correct enough to increase its use of Rule I above the average of 50%. On the other hand, Figure 3.4a achieved Rule IV at trial four where it continued to only use that rule. The model achieved this by being incorrect with No Rule on the second trial and incorrect with Rule I on the third trial. This is consistent with Siegler's data in that some children never achieved conservation while others understood it from a young age. It is also consistent with the idea that a simulation that gets answers incorrect in the first few trials is, overall, more successful than one that gets the answers correct.

4 Discussion

The model wasn't able to replicate the results of Siegler's study exactly. This could imply that not all aspects of conservation were included in the operationalised theoretical model. For example, prospective memory strategies in the final version of the model weren't mentioned in Siegler's operationalised theoretical model. Prospective memory could be a strategy that children use in between trials to evaluate their current situation. Instead of disregarding the rule when the model was incorrect, it should disregard when it knows the rule doesn't



(a) Simulation that did reach Rule IV



(b) Simulation that didn't achieve Rule IV

Figure 3.4: Individual Trials of Number Conservation with the Instance Based Learning with Prospective Memory Model

work in several situations. The rule could be evaluated in terms of how much evidence is against the rule as well as the current activation of the rule. If the rule has a high level of activation but the evidence shows that the rule does not work, the model should disregard that rule in favour of a better rule. This idea could be implemented through the use of prospective memory.

Siegler's operationalised theoretical model should be expanded to consider what children do with correct and incorrect answers. If the child stores correct answers, does it compare them to new situations and try to apply the same strategy, does it try to generalise the strategy to apply to all situations, or does it not do anything with the knowledge? Equally, with incorrect answers, does the child consider why it got the answer incorrect? These aspects of theory of mind aren't grasped until the age of four when children realise that beliefs can be wrong (Astington and Edward, 2010). Conservation challenges a child's belief and forces them to think differently which can be a difficult task as children have to understand why they are wrong rather than how they can be correct. This aspect is especially important when trying to conserve.

The idea of building a model that is more successful when it gets answers incorrect seems counterintuitive. Yet, this is something that can be observed in the model (Figure 3.4a). This isn't something that would be considered logical. A child that consistently gets answers incorrect most likely shows little understanding for the situation and won't be capable of conservation. As well as considering what do to with an incorrect response, an operationalised model should also consider what to do when the model is consistently incorrect. A model that is consistently incorrect should not be able to conserve.

Although this model was generalised to cover three different types of conservation, the variables such as responses and questioning style was limited. Many studies have shown that the way in which the experimenter ask the question has a large influence in the child's understanding (Goodnow, 1973). When a child is encouraged to justify their response, a leading statement could cause the child to reason differently about their answers. Equally children could give answers that were of Rule III standard, their reasoning skills were of Rule I or Rule II level (Gelman, 1969).

One aspect which is often mentioned in connection with number conservation is counting. Counting is often cited as the reason as to why number conservation develops earlier than other types of conservation (Siegler, 1981, p.51). Even in Siegler's adjusted model (Siegler, 1981, Figure 9) it is unclear where counting would fit in. There needs to be a distinction between conservation counting and non-conservation counting. A child that only counts the extra objects that appear after the transition to give a precise answer has more understanding of conservation than a child who has to count both rows of objects before and after the transition to confirm that a change as occurred.

A child that can count will perform the same as a child who uses Rule IV. Both children get the same number of questions correct yet the child using Rule

IV has an understanding of conservation while the counting child doesn't. The latter child has no incentive to improve its method unless it encounters a similar experience where counting cannot be applied, such as pouring the same amount of liquid into multiple different sized glasses.

In the studies about conservation mentioned in this paper, the response time of the children and the correctness of the answer was not recorded. Obviously it must be noted that timing young children can be difficult but timing them could lead to insights about what conservation method they are using. A child that fully understands conservation would be able to answer instantly in comparison to a child who has to count. Both children would be correct but the counting child would have a slower response time. This slower response shows that the child has less understanding for conservation than the other child.

A limitation of the model is that it learns each new conservation rule in the simulated environment of the experiment. Although children are capable of improving their conservation abilities through several trials, it is unlikely that children learn this way in a natural environment. A natural environment being one where the child isn't constantly utilised by a researcher to be a participant in a conservation experiment. Although the probability of a of three-year-old child using a conservation rule was encoded in the model, this doesn't fully explore the environment or the interactions children perform to improve their implicit understanding of conservation outside of the experiment trial setting.

Rather than only being able to conserve under instruction from a researcher, it is more likely that the child will have transferred knowledge and applied it conservation strategies through interacting with its natural environment. Knowledge transfer would be expected between liquid and solid conservation since they achieve similar results in experiments (Siegler, 1981). Strategies such as counting will only facilitate knowledge transfer to number conservation other since it uses discrete variables which are suitable for counting.

5 Conclusion

The research question of this paper was: "Is it possible to build a model of conservation, based on Siegler's operationalised model and results, which can accurately represent conservation development?". An operationalised model has been built based on Siegler's operationalised but the same results were not achieved. The model failed to replicate the same pattern of rule use as Siegler's results show. The model was adjusted to use different learning strategies and methods but this did not improve the results. This leads to the conclusion that there are more aspects to conservation development than were included in the operationalised model. This leads to an opportunity to improve the current operationalised theoretical model, and research question, to include aspects such as prospective memory and counting, as well as performing conservation experiments that include answer correctness and response time.

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