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Multiple Context

The aim of this essay is to remove any misunderstanding of the power of a multiple context. I had not realized before that people reading my two books might think that the teaching of PURR-PUSS depends on the careful selection of Cortical Areas (formerly called Templates). In every example given in my two books, the Cortical Areas used were the minimum necessary, both because of the severe limits on computation at the time and also to make the examples as simple as possible to follow.

The collection of Cortical Areas (CAs) provided for a particular robot body is called the **multiple context** of the system. Each CA has a fixed set of event types which it contributes as a context type to the multiple context. I will use experiments with the "Numbers in the Head" robot described in chapter 4 of my *Associative Learning for a Robot Intelligence* to illustrate the points made in my discussion. I will not be repeating the discussion in that chapter which went far beyond the basics that I am explaining here. Indeed, I will not even mention again the stimulus-predicting CAs that were essential to the discussion that justified the chapter heading "Numbers in the Head".

The robot (with a PP brain) could see, speak, hear and move its finger in the simplest of ways. Its world consisted of three displays with one button each. Each display showed one of the digits 0, 1, 2 and 3. When the display's button was pressed by the robot's finger, the displayed digit advanced from 0 to 1, 1 to 2, 2 to 3, or 3 to 0. Each display, therefore, incorporated a counter that implemented single digit modulo-4 counting. The three buttons and displays were called "hundreds", "tens" and "units". The first task taught to the PP robot was to count modulo-4 with the three displays. Since the displays implemented the modulo-4 counting of each digit, all that PP had to learn was to carry 1 from the units display to the tens display when the units display passed from 3 to 0, and to carry 1 from the tens display to the hundreds display when the tens display passed from 3 to 0. PP also had to say what was on the displays in between adding one to the units display.

The robot body had three action event types and three stimulus event types. The three action event types were *Move, Look* and *Say.* The three stimulus event types were *Foveal, Global* and *Hear.* The events possible in each event type are shown below:

Move: Press Units button (PU), Press Tens button (PT), Press Hundreds button (PH), and Close Finger (CF).
Look: Look Units display (LU), Look Tens display (LT), Look Hundrds display (LH), and Close Eyes (LC).
Say: Sounds including "No" (0), "One" (1), "Two" (2), "Three" (3), "Unit" (4), "Units" (5), "Ten" (6), "Tens" (7), "Hundred" (8), "Hundreds" (9) and "Repeat" (10).

Foveal: '0', '1', '2', '3' when the eyes are seeing a digit, and '=', when the eyes are closed.

Global: 'U', 'T' and 'H' when the eyes are looking at the units, tens and hundreds display, respectively. Again, '=" is the stimulus when the eyes are closed.
Hear: The same sounds as can be said.

The robot performs one action on each **step,** the action being either a *Move* action, a *Look* action or a *Say* action. After each action, the stimuli of the three stimulus types are given by the robot body to PP. So a step comprises an action and three simultaneous stimuli.

PP is taught by what I call **soft teaching.** If PP selects an action, then Teacher watches and is not allowed to intervene. If PP cannot select an action, Teacher can provide one or allow the step to pass with no action (null action). It is not, of course, reasonable to have Teacher move a robot's eyes, so we assume that the robot has a reflex and if Teacher points to one of the displays, the robot will automatically move its eyes to that display. The effect is the same so in the computer simulation Teacher provides the eye action. In some other cases (e.g. chapter 6) reflexes have been simulated. There is also a problem with Teacher saying things for PP, but here the solution is different. We assume that when PP hears a sound from Teacher, it stores the sound as though it had said it. I call this **mimic speech** and it is not unlikely that even humans have some built-in connection between voice and hearing. [However, the main justification is that we haven't time to explore the possibilities of learning such a connection through random babbling.]

The action-predicting CAs in the multiple context used in the experiment in chapter 4 of the book are

Multiple Context -1

HM:	Hear(step-2),	Look(step-1)	>>Move(step)
ML:	Move(step-2),	Hear(step-1)	>>Look(step)
HL:	Hear(step-2),	Hear(step-1)	>>Look(step)
LS:	Look(step-2),	Hear(step-1)	>>Say(step)
MS:	Move(step-1),	Foveal(step-1)	>> Say(step)
HS:	Hear(step-2),	Look(step-1), Foveal(step-1)	>> Say(step)

Let me explain what this multiple context means. The first CA, called HM, says that **if** the action of the current step is a *Move,* the action of the previous step was a *Look,* and the stimulus of the step before that was a *Hear*, **then** store these three events as an association in memory. The two event types to the left of the double arrowhead >> define the **context** of an association, while the event type to the right defines the **associated event.** A similar explanation applies to the others. Note that in the last CA, called HS, the *Look* action and *Foveal* stimulus are taken from the same step, which is possible because a step comprises an action and the immediately following stimuli.

As I said above, Multiple Context-1 is the minimum needed for learning the counting algorithm.

A number of general statements can be made about a multiple context. We will be primarily concerned with the computational power and learnability provided by a multiple context.

1. In general, the more CAs there are in a multiple context, the more PP can do with it, but the more computing time is needed. If the system is a parallel computer (like the PP design, but not its simulation on a serial machine), then more hardware is needed, rather than more computing time.

2. Strong CAs increase computational power and the complexity of algorithms that can be learned.

3. Weak CAs encourage generalization and make learning more difficult if they are weaker than is needed for the task in hand. In this case, some form of punishment or disapproval is needed to paralyse the unwanted generalizations. (A generalization is an assumption that something which happens in one situation applies to a wider set of assumptions. Smaller contexts match more situations than large contexts so they generalize more.)

4. The strength of a CA is difficult to define because it depends on the other CAs in the multiple context, but if the context of one CA is a proper subset of the context of another CA, then the first is definitely weaker than the second.

5. To learn a task with a multiple context is to acquire in memory all the associations needed for the task. This learning can be achieved in innumerable ways extending from a linear process of carrying out the whole task with all its ramifications in one long sequence, through learning the task in parts, to learning each association separately. Although the first method was used in the book for the Numbers in the Head task, it will only be practical for simple tasks. Learning each association separately is also usually impractical because it requires knowledge of the associations and the contents of PP's memory. The natural and efficient way of teaching PP is to take it through the difficult bits and help it when it gets stuck.

Returning to Multiple Context-1, we can see the effect of enlarging this minimum multiple context. With Multiple Context-1, the task can be taught with little difficulty. Multiple Context-2 includes four extra CAs, LHM, HHM, HML and MLS:

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HM:  Hear(step-2),      Look(step-1)                    >>Move(step)
ML:  Move(step-2),      Hear(step-1)                    >>Look(step)
HL:  Hear(step-2),      Hear(step-1)                    >>Look(step)
LS:  Look(step-2),      Hear(step-1)                    >>Say(step)
MS:  Move(step-1),      Foveal(step-1)                  >> Say(step)
HS:  Hear(step-2),  Look(step-1),  Foveal(step-1)       >> Say(step)

LHM: Look(step-2),      Hear(step-1)                    >>Move(step)
HHM: Hear(step-2),      Hear(step-1)                    >>Move(step)
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HML: Hear(step-2), Move(step-1) >>Look(step)
MLS: Move(step-2), Look(step-1) >>Say(step)

Multiple Context-2 includes four CAs that might have been seen by a reader to have been excluded from the original Multiple Context-1 because they would interfere with main ones. Actually, their inclusion causes no interference at all; indeed, if these are included none of them cause any associations to be stored with the teaching of the modulo-4 counting task. Of course, although they are harmless in the learning of that task, their presence could allow PP to learn other tasks which it could not learn without them.

An unlimited number of multiple contexts could be formed by including CAs with stronger contexts, i.e. CAs with contexts that are supersets of the contexts in Multiple Context-1. These CAs would also not affect the teaching of the modulo-4 counting task, but could give PP much greater computational power, up to Turing Machine power. But that would be a waste with such a limited robot body.

There is only one kind of extension of the Multiple Context that affects the teaching of the modulo-4 counting task and that is the addition of weaker CAs. The rest of this account is devoted to showing that even with weaker CAs the task can still be taught, but we have to have some kind of punishment to neutralize their unwanted generalizations while the stronger CAs take over. I will call this mild form of punishment "disapproval". It is always vital to give stronger CAs priority over weaker CAs in action-selection or prediction. There will also be some associations of the stronger CAs caused by the generalizations of the weaker ones, and disapproval will paralyse these. There is nothing difficult about the teaching with disapproval. When PP makes a mistake, it is disapproved and then taken through the same part of the task again. The second time it will not repeat the wrong action because of the disapproval so Teacher has the chance to lead it through the correct actions. That has the additional effect of removing the disapproval on the weaker associations, which are now harmless because of the over-riding stronger associations.

Teaching the Modulo-4 Task in Parts

Multiple Context-3 includes four weaker Cortical Areas (CAs), XLM, XHL, XHS and XLS:

HM: Hear(step-2), Look(step-1) >>Move(step)
ML: Move(step-2), Hear(step-1) >>Look(step)
HL: Hear(step-2), Hear(step-1) >>Look(step)
LS: Look(step-2), Hear(step-1) >>Say(step)
MS: Move(step-1), Foveal(step-1) >> Say(step)
HS: Hear(step-2), Look(step-1), Foveal(step-1) >> Say(step)

XLM: Look(step-1) >>Move(step)
XHL: Hear(step-1), >>Look(step)

XHS: Hear(step-1) >>Say(step)
XLS: Look(step-1), Foveal(step-1) >>Say(step)

The extra CA called XLM is a subset of HM. XHL is a subset of both ML and HL. XHS is a subset of LS. XLS is a subset of HS. There is no subset of MS, but it is already a one step context.

In spite of these weak CAs we will be able to teach PP the modulo-4 counting task in 400 steps with only 15 disapprovals. The teaching will be done "in parts" to illustrate one of the many ways in which that can be done. The parts will be separated by "null actions", which correspond to Teacher doing nothing for a step when PP cannot select an action. At times, Teacher will reset the counters in the displays to some particular combination of digits to focus the teaching on particular parts of the task.

The whole teaching run is given in the Appendix, together with the memory of associations acquired after step 402. We can see the effects of the weaker CAs in the first 30 steps, so I will explain the terminology of the listing in the Appendix. The first few lines are as follows:

Step	Keystrokes	Meaning	HTL Counters	CAs	Extra
			000 <set		
1	CW10?	RP= "Repeat"			
2	CLH	LH= Look Hundreds			**0XHL**
3	CW0?	NO= "No"		**1HS**	**2XLS**
4	CW9?	HS= "Hundreds"		**3LS**	**4XHS**
5	**CX**	Null Action	**100 <set**		
6	CW10?	RP= "Repeat"			
7	C	LH= Look Hundreds			0XHL
8	CW1?	ON= "One"		**5HS**	**6XLS**
9	CW8?	HD= "Hundred"		**7LS**	**8XHS**
10	**CX**	Null Action	**200 <set**		

The first column gives the step number. The second column gives the Teacher's keystrokes. Nothing happens until Teacher hits the key C for 'continue', so every entry begins with C. If PP can select its own action, then it will do so. Otherwise, Teacher is given the choice of a W(ord), L(ook) or M(ove). Having picked one of these, the choice of particular event is offered. On the first line, we see Teacher has chosen W for Word and then 10 (? for Enter key) which is the code for the word "Repeat", as is confirmed in the third column. The fourth column shows the state of the three display counters, Hundreds, Tens and Units in that order. These are set to 000 at the start, as shown. The fifth and sixth columns show the numbers of the contexts either contributing to the selection of action or being acquired. New contexts are given in bold type. The numbering of the contexts is in order of acquisition with the name of the CA responsible. The first context acquired is **0XHL** by the CA XHL, because the context specified by that CA only requires a sound to be heard on the previous step. If we look in the Appendix, it will be seen that 0XHL has one association RP >> LH, agreeing with the abbreviations of events in the third column: The context is the word "Repeat" from step 0 and the associated event is the Look Hundreds action in step 1, as required by the CA.

In this first part of the teaching, PP is being shown how to say what is on the Hundreds display by looking at it and then saying what it sees. In the first four steps this has been done for a 0 on the Hundreds display. On step 5 Teacher is given the chance to give a null action (pause), set the Hundreds display to 1 and then show PP how to describe that. But on step 7, PP takes over and does the action Look Hundreds on its own. PP's own actions are underlined. We see from the fifth and sixth columns that this was made possible by the already acquired context 0XHL and its associated event. By chance, the weak CA has selected the correct action so no disapproval is needed and Teacher is saved the trouble of choosing the action.

On step 24, the selection of "Hundreds" by the weaker CA is not appropriate. It is a poor generalization based on too small a context. We are now teaching PP to look at the Tens display and say what it sees.

11	CW10?	RP= "Repeat"				
12	C	LH= Look Hundreds			0XHL	
13	CW2?	TW= "Two"		**9HS**	**10XLS**	
14	CW9?	HS= "Hundreds"		**11LS**	**12XHS**	
15	**CX**	Null Action	**300 <set**			
16	CW10?	RP= "Repeat"				
17	C	LH= Look Hundreds			0XHL	
18	CW3?	TH = "Three"		**13HS**	**14XLS**	
19	CW9?	HS= "Hundreds"		**15LS**	**16XHS**	
20	**CX**	Null Action	**000 <set**			
21	CW9?	HS= "Hundreds"				
22	CLT	LT= Look Tens			**17XHL**	
23	CW0?	NO= "No"		**18HS**	**19XLS**	
24	**C**	HS= "Hundreds"		**20LS**	4XHS	**Disapproval**
25	CX	Null Action				

On step 3 after saying "No" it was appropriate to say "Hundreds" because PP was looking at the Hundreds display, but on step 24 PP is looking at the Tens display and "Hundreds" is no long correct. The weak context of 4XHS only goes back to the "NO" so it cannot distinguish between looking at the two displays. Its "generalization" from one situation to the next is too liberal. PP chooses the action selected by it and this causes the stronger context **20LS** to be wrongly acquired. Teacher disapproves the action, which gives both associations,

4XHS: NO >> HS and 20LS: LT, NO >> HS,

a disapproval mark. Teacher does a null action and takes PP through the last sequence again.

26	CW9?	HS= "Hundreds"				
27	C	LT= Look Tens			17XHL	
28	C	NO= "No"		18HS	19XLS	
29	CW7?	TS= "Tens"		20LS	4XHS	
30	**CX**	Null Action	**010 <set**			

This time PP can do the Look Tens and "No" actions by itself but comes to a halt with the disapproved associations. Teacher gives the required "Tens" and both of the contexts acquire new and correct associations:

4XHS:	NO >> HS (disapproved)	20LS:	LT, NO >> HS (disapproved)
	NO >> TS		**LT, NO >> TS**

The next time that "No" is followed correctly by "Hundreds", the 4XHS association will lose its disapproval, but by then the stronger 3LS and 20LS associations will be in control. The disapproved 20LS association will remain disapproved.

This little sequence demonstrates how the weaker CAs interfere (sometimes helping and sometimes not) with the learning of the stronger CAs, and also shows how the interference is neatly removed by disapproval. **It is important to note that the Teacher does not have to know what is happening at the association level in order to disapprove. By disapproving incorrect actions and subsequently leading PP through the correct actions all the appropriate changes at association level automatically occur.** We have looked at the association level to explain what is happening.

There are many ways in which humans show disapproval of the actions of other humans. Certain facial expressions and tones of voice are particularly common. It is likely that the negaative reaction to these expressions and tones is innate, so it is not unreasonable to equip a robot with similar reactions.

The reader shouldn't find it difficult to work out what happens in the rest of the teaching, using the listing and the memory at the end. It will be obvious that the task could be taught in innumerable ways by breaking it up into different parts.

Appendix

Step	Keystrokes	Meaning	HTL Counters	CAs	Extra
1	CW10?	RP= "Repeat"			
2	CLH	LH= Look Hundreds			**0XHL**
3	CW0?	NO= "No"		**1HS**	**2XLS**
4	CW9?	HS= "Hundreds"		**3LS**	**4XHS**
5	**CX**	Null Action	**100 <set**		
6	CW10?	RP= "Repeat"			
7	C	LH= Look Hundreds			0XHL
8	CW1?	ON= "One"		**5HS**	**6XLS**
9	CW8?	HD= "Hundred"		**7LS**	**8XHS**
10	**CX**	Null Action	**200 <set**		
11	CW10?	RP= "Repeat"			
12	C	LH= Look Hundreds			0XHL
13	CW2?	TW= "Two"		**9HS**	**10XLS**
14	CW9?	HS= "Hundreds"		**11LS**	**12XHS**
15	**CX**	Null Action	**300 <set**		
16	CW10?	RP= "Repeat"			
17	C	LH= Look Hundreds			0XHL
18	CW3?	TH = "Three"		**13HS**	**14XLS**
19	CW9?	HS= "Hundreds"		**15LS**	**16XHS**
20	**CX**	Null Action	**000 <set**		

21	CW9?	HS= “Hundreds”				
22	CLT	LT= Look Tens			**17XHL**	
23	CW0?	NO= “No”		**18HS**	**19XLS**	
24	**C**	HS= “Hundreds”		**20LS**	4XHS	**Disapprove**
25	CX	Null Action				
26	CW9?	HS= “Hundreds”				
27	C	LT= Look Tens			17XHL	
28	C	NO= “No”		18HS	19XLS	
29	CW7?	TS= “Tens”		20LS	4XHS	
30	**CX**	Null Action	**010 <set**			
31	CW9?	HS= “Hundreds”				
32	C	LT= Look Tens			17XHL	
33	CW1?	ON= “One”		**21HS**	**22XLS**	
34	**C**	HD= “Hundred”		**23LS**	8XHS	**Disapprove**
35	CX	Null Action				
36	CW9?	HS= “Hundreds”				
37	C	LT= Look Tens			17XHL	
38	C	ON= “One”		21HS	22XLS	
39	CW6?	TN= “Ten”		23LS	8XHS	
40	**CX**	Null Action	**020 <set**			
41	CW9?	HS= “Hundreds”				
42	C	LT= Look Tens			17XHL	
43	CW2?	TW= “Two”		**24HS**	**25XLS**	
44	**C**	HS= “Hundreds”		**26LS**	12XHS	**Disapprove**
45	CX	Null Action				
46	CW9?	HS= “Hundreds”				
47	C	LT= Look Tens			17XHL	
48	C	TW= “Two”		24HS	25XLS	
49	CW7?	TS= “Tens”		26LS	12XHS	
50	**CX**	Null Action	**030 <set**			
51	CW9?	HS= “Hundreds”				
52	C	LT= Look Tens			17XHL	
53	CW3?	TH= “Three”		**27HS**	**28XLS**	
54	C	HS= “Hundreds”		**29LS**	16XHS	**Disapprove**
55	CX	Null Action				
56	CW9?	HS= “Hundreds”				
57	C	LT= Look Tens			17XHL	
58	C	TH= “Three”		27HS	28XLS	
59	CW7?	TS= “Tens”		29LS	16XHS	
60	**CX**	Null Action	**000 <set**			
61	CW8?	HD= “Hundred”				
62	CLT	LT= Look Tens			**30XHL**	
63	C	NO= “No”		**31HS**	19XLS	
64	C	TS= “Tens”		20LS	4XHS	
65	**CX**	Null Action	**010 <set**			
66	CW8?	HD= “Hundred”				
67	C	LT= Look Tens			30XHL	
68	C	ON= “One”		**32HS**	22XLS	
69	C	TN= “Ten”		23LS	8XHS	
70	**CX**	Null Action	**020 <set**			
71	CW8?	HD= “Hundred”				
72	C	LT= Look Tens			30XHL	
73	C	TW= “Two”		**33HS**	25XLS	
74	C	TS= “Tens”		26LS	12XHS	
75	CX	Null Action	**030 <set**			
76	CW8?	HD= “Hundred”				

77	C	LT= Look Tens			30XHL	
78	C	TH= “Three”		**34HS**	28XLS	
79	C	TS= “Tens”		29LS	16XHS	
80	**CX**	Null Action	**000 <set**			
81	CW7?	TS= “Tens”				
82	CLU	LU= Look Units			35XHL	
83	CW0?	NO= “No”		**36HS**	**37XLS**	
84	C	TS= “Units”			4XHS	**Disapprove**
85	**CX**	Null Action				
86	CW7?	TS= “Tens”				
87	C	LU= Look Units			35XHL	
88	C	NO= “No”		36HS	37XLS	
89	CW5?	US= “Units”		**38LS**	4XHS	
90	**CX**	Null Action	**001 <set**			
91	CW7?	TS= “Tens”				
92	C	LU= Look Units			35XHL	
93	CW1?	ON= “One”		**39HS**	**40XLS**	
94	C	TN= “Ten”		**41LS**	8XHS	**Disapprove**
95	**CX**	Null Action				
96	CW7?	TS= “Tens”				
97	C	LU= Look Units			35XHL	
98	C	ON= “One”		39HS	40XLS	
99	CW4?	UN= “Unit”		41LS	8XHS	
100	**CX**	Null Action	**002 <set**			
101	CW7?	TS= “Tens”				
102	C	LU= Look Units			35XHL	
103	CW2?	TW= “Two”		**42HS**	**43XLS**	
104	C	TS= “Tens”		**44LS**	12XHS	**Disapprove**
105	**CX**	Null Action				
106	CW7?	TS= “Tens”				
107	C	LU= Look Units			35XHL	
108	C	TW= “Two”		42HS	43XLS	
109	CW5?	US= “Units”		44LS	12XHS	
110	**CX**	Null Action	**003 <set**			
111	CW7?	TS= “Tens”				
112	C	LU= Look Units			35XHL	
113	CW3?	TH= “Three”		**45HS**	**46XLS**	
114	C	TS= “Tens”		**47LS**	16XHS	**Disapprove**
115	**CX**	Null Action				
116	CW7?	TS= “Tens”				
117	C	LU= Look Units			35XHL	
118	C	TH= “Three”		45HS	46XLS	
119	CW5?	US= “Units”		47LS	16XHS	
120	**CX**	Null Action	**000 <set**			
121	CW6	TN= “Ten”				
122	CLU	LU= Look Units			**48XHL**	
123	C	NO= “No”		**49HS**	37XLS	
124	C	US= “Units”		38LS	4XHS	
125	**CX**	Null Action	**001 <set**			
126	CW6?	TN= “Ten”				
127	C	LU= Look Units			48XHL	
128	C	ON= “One”		**50HS**	40XLS	
129	C	UN= “Unit”		41LS	8XHS	
130	**CX**	Null Action	**002 <set**			
131	CW6?	TN= “Ten”				
132	C	LU= Look Units			48XHL	

133	C	TW= “Two”		**51HS**	43XLS	
134	C	US= “Units”		44LS	12XHS	
135	**CX**	Null Action	**003 <set**			
136	CW6?	TN= “Ten”				
137	C	LU= Look Units			48XHL	
138	C	TH= “Three”		**52HS**	46XLS	
139	C	US= “Units”		47LS	16XHS	
140	**CX**	Null Action	**000 <set**			
141	CW5?	US= “Units”				
142	CLU	LU= Look Units			**53XHL**	
143	C	NO= “No”		**54HS**	37XLS	**Disapprove**
144	**CX**	Null Action				
145	CW5?	US= “Units”				
146	C	LU= Look Units			53XHL	
147	CMU	PU= Press Units	001	**55HM**	**56XLM**	
148	CW10?	RP= “Repeat”		**57MS**		
149	C	LH= Look Hundreds		**58ML**	0XHL	
150	C	NO= “No”		1HS	2XHL	
151	C	HS= “Hundreds”		3LS	4XHS	
152	C	LT= Look Tens		**59HL**	17XHL	
153	C	NO= “No”		18HS	19XLS	
154	C	TS= “Tens”		20LS	4XHS	
155	C	LU= Look Units		**60HL**	35XHL	
156	C	ON= “One”		39HS	40XLS	
157	C	UN= “Unit”		41LS	8XHS	
158	CX	Null Action	**003 <set**			
159	CW5?	US= “Units”				
160	C	LU= Look Units			53XHL	
161	C	PU= Press Units	000	55HM	56XLM	
162	CW7?	TS= “Tens”		**61MS**		
163	C	LU= Look Units		**62ML**	35XHL	**Disapprove**
164	CX	Null Action	**003 <set**			
165	CW5?	US= “Units”				
166	C	LU= Look Units			53XHL	
167	C	PU= Press Units	000	55HM	56XLM	
168	C	TS= “Tens”		61MS		
169	CLT	LT= Look Tens		62ML	35XHL	
170	C	NO= “No”		**63HS**	19XLS	**Disapprove**
171	CX	Null Action	**003 <set**			
172	CW5?	US= “Units”				
173	C	LU= Look Units			53XHL	
174	C	PU= Press Units	000	55HM	56XLM	
175	C	TS= “Tens”		61MS		
176	C	LT= Look Tens		62ML	35XHL	
177	CMT	PT= Press Tens	010	**64HM**	**65XLM**	
178	CX	Null Action	**033 <set**			
179	CW5?	US= “Units”				
180	C	LU= Look Units			53XHL	
181	C	PU= Press Units	030	55HM	56XLM	
182	C	TS= “Tens”		61MS		
183	C	LT= Look Tens		62ML	35XHL	
184	C	PT= Press Tens	000	64HM	65XLM	
185	CW9?	HS= “Hundreds”		**66MS**		
186	C	LT= Look Tens		**67ML**	17XHL	**Disapprove**
187	CX	Null Action	**033 <set**			
188	CW5?	US= “Units”				

189	C	LU= Look Units			53XHL	
190	C	PU= Press Units	030	55HM	56XLM	
191	C	TS= “Tens”		61MS		
192	C	LT= Look Tens		62ML	35XHL	
193	C	PT= Press Tens	000	64HM	65XLM	
194	C	HS= “Hundreds”		66MS		
195	CLH	LH= Look Hundreds		67ML	17XHL	
196	C	NO= “No”		**68HS**	2XLS	**Disapprove**
197	CX	Null Action	**033 <set**			
198	CW5?	US= “Units”				
199	C	LU= Look Units			53XHL	
200	C	PU= Press Units	030	55HM	56XLM	
201	C	TS= “Tens”		61MS		
202	C	LT= Look Tens		62ML	35XHL	
203	C	PT= Press Tens	000	64HM	65XLM	
204	C	HS= “Hundreds”		66MS		
205	C	LH= Look Hundreds		67ML	17XHL	
206	CMH	PH= Press Hundreds	100	**69HM**	**70XLM**	
207	CX	Null Action	**000 <set**			
208	CW0?	NO= “No”				
209	C	HS= “Hundreds”			4XHS	
210	C	LT= Look Tens		59HL	17XHL	
211	C	NO= “No”		18HS	19XLS	
212	C	TS= “Tens”		20LS	4XHS	
213	C	LU= Look Units		60HL	35XHL	
214	C	NO= “No”		36HS	37XLS	
215	C	US= “Units”		38LS	4XHS	
216	C	LU= Look Units		**71HL**	53XHL	**Disapprove**
217	CX	Null Action	**000 <set**			
218	CW7?	TS= “Tens”				
219	C	LT= Look Tens			35XHL	
220	C	PT= Press Tens	010	64HM	65XLM	
221	CX	Null Action	**000 <set**			
222	CW0?	NO= “No”				
223	C	HS= “Hundreds”			4XHS	
224	C	LT= Look Tens		59HL	17XHL	
225	C	NO= “No”		18HS	19XLS	
226	C	TS= “Tens”		20LS	4XHS	
227	C	LU= Look Units		60HL	35XHL	
228	C	NO= “No”		36HS	37XLS	
229	C	US= “Units”		38LS	4XHS	
230	CLC	LC= Close Eyes		71HL	53XHL	
231	CX	Null Action	**001 <set**			
232	CW0?	NO= “No”				
233	C	US= “Units”			4XHS	
234	C	LC= Close Eyes		71HL	53XHL	
235	CX	Null Action	**111 <set**			
236	CW1?	ON= “One”				
237	C	UN= “Unit”			8XHS	
238	CLC	LC= Close Eyes		**72HL**	**73XHL**	
239	CMC	CF= Close Finger		**74HM**	**75XLM**	
240	CX	Null Action	**111 <set**			
241	CW10?	RP= “Repeat”				
242	C	LH= Look Hundreds			0XHL	
243	C	ON= “One”		5HS	6XLS	
244	C	HD= “Hundred”		7LS	8XHS	

245	C	LT= Look Tens		**76HL**	30XHL	
246	C	ON= “One”		32HS	22XLS	
247	C	TN= “Ten”		23LS	8XHS	
248	C	LU= Look Units		**77HL**	48XHL	
249	C	ON= “One”		50HS	40XLS	
250	C	UN= “Unit”		41LS	8XHS	
251	C	LC= Close Eyes		72HL	73XHL	
252	C	CF= Close Finger		74HM	75XLM	
253	CX	Null Action	**222 <set**			
254	CW10?	RP= “Repeat”				
255	C	LH= Look Hundreds			0XHL	
256	C	TW= “Two”		9HS	10XLS	
257	C	HS= “Hundreds”		11LS	12XHS	
258	C	LH= Look Hundreds		**78HL**	17XHL	**Disapprove**
259	CX	Null Action	**222 <set**			
260	CW10?	RP= “Repeat”				
261	C	LH= Look Hundreds			0XHL	
262	C	TW= “Two”		9HS	10XLS	
263	C	HS= “Hundreds”		11LS	12XHS	
264	CLT	LT= Look Tens		78HL	17XHL	
265	C	TW= “Two”		24HS	25XLS	
266	C	TS= “Tens”		26LS	12XHS	
267	C	LU= Look Units		**79HL**	35XHL	
268	C	TW= “Two”		42HS	43XLS	
269	C	US= “Units”		44LS	12XHS	
270	C	LC= Close Eyes		**80HL**	53XHL	
271	C	CF= Close Finger		**81HM**	75XLM	
272	CX	Null Action	**333 <set**			
273	CW10?	RP= “Repeat”				
274	C	LH= Look Hundreds			0XHL	
275	C	TH= “Three”		13HS	14XLS	
276	C	HS= “Hundreds”		15LS	16XHS	
277	CLT	LT= Look Tens		**82HL**	17XHL	
278	C	TH= “Three”		27HS	28XLS	
279	C	TS= “Tens”		29LS	16XHS	
280	CLU	LU= Look Units		**83HL**	35XHL	
281	C	TH= “Three”		45HS	46XLS	
282	C	US= “Units”		47LS	16XHS	
283	CLC	LC= Close Eyes		**84HL**	53XHL	
284	C	CF= Close Finger		81HM	75XLM	
285	CX	Null Action	**001 <set**			
286	CLU	LU= Look Units				
287	CMU	PU= Press Units	002		56XLM	
288	CW10?	RP= “Repeat”		**85MS**		
289	C	LH= Look Hundreds		58ML	0XHL	
290	C	NO= “No”		1HS	2XLS	
291	C	HS= “Hundreds”		3LS	4XHS	
292	C	LT= Look Tens		59XL	17XHL	
293	C	NO= “No”		18HS	19XLS	
294	C	TS= “Tens”		20LS	4XHS	
295	C	LU= Look Units		60HL	35XHL	
296	C	TW= “Two”		42HS	43XLS	
297	C	US= “Units”		44LS	12XHS	
298	C	LC= Close Eyes		80HL	53XHL	
299	C	CF= Close Finger		81HM	75XLM	
300	CW5?	US= “Units”		**86MS**		

301	CLU	LU= Look Units		**87ML**	53XHL
302	C	PU= Press Units	003	55HM	56XLM
303	CW10?	RP= “Repeat”	**003 <set**	**88MS**	
304	C	LH= Look Hundreds		58ML	0XHL
305	C	NO= “No”		1HS	2XLS
306	C	HS= “Hundreds”		3LS	4XHS
307	C	LT= Look Tens		59XL	17XHL
308	C	NO= “No”		18HS	19XLS
309	C	TS= “Tens”		20LS	4XHS
310	C	LU= Look Units		60HL	35XHL
311	C	TW= “Two”		45HS	46XLS
312	C	US= “Units”		47LS	16XHS
313	C	LC= Close Eyes		84HL	53XHL
314	C	CF= Close Finger		81HM	75XLM
315	C	US= “Units”		86MS	
316	C	LU= Look Units		87ML	53XHL
317	C	PU= Press Units	000	55HM	56XLM
318	C	TS= “Tens”		61MS	
319	C	LT= Look Tens		62ML	35XHL
320	C	PT= Press Tens	010	64HM	65XLM
321	CW10?	RP= “Repeat”		**89MS**	
322	CX	Null Action	**013 <set**		
323	CW5?	US= “Units”			
324	CLU	LU= Look Units			53XHL
325	C	PU= Press Units	010	55HM	56XLM
326	C	TS= “Tens”		61MS	
327	C	LT= Look Tens		62ML	35XHL
328	C	PT= Press Tens	020	64HM	65XLM
329	CW10?	RP= “Repeat”		**90MS**	
330	CX	Null Action	**023 <set**		
331	CW5?	US= “Units”			
332	CLU	LU= Look Units			53XHL
333	C	PU= Press Units	020	55HM	56XLM
334	C	TS= “Tens”		61MS	
335	C	LT= Look Tens		62ML	35XHL
336	C	PT= Press Tens	030	64HM	65XLM
337	CW10?	RP= “Repeat”		**91MS**	
338	CX	Null Action	**033 <set**		
339	CW5?	US= “Units”			
340	CLU	LU= Look Units			53XHL
341	C	PU= Press Units	030	55HM	56XLM
342	C	TS= “Tens”		61MS	
343	C	LT= Look Tens		62ML	35XHL
344	C	PT= Press Tens	000	64HM	65XLM
345	C	HS= “Hundreds”		66MS	
346	C	LH= Look Hundreds		67ML	17XHL
347	C	PH= Press Hundreds	100	69HM	70XLM
348	CW10?	RP= “Repeat”		**92MS**	
349	CX	Null Action	**133 <set**		
350	CW5?	US= “Units”			
351	CLU	LU= Look Units			53XHL
352	C	PU= Press Units	130	55HM	56XLM
353	C	TS= “Tens”		61MS	
354	C	LT= Look Tens		62ML	35XHL
355	C	PT= Press Tens	100	64HM	65XLM
356	C	HS= “Hundreds”		66MS	

357	C	LH= Look Hundreds		67ML	17XHL
358	C	PH= Press Hundreds	200	69HM	70XLM
359	CW10?	RP= “Repeat”		**93MS**	
360	CX	Null Action	**233 <set**		
361	CW5?	US= “Units”			
362	CLU	LU= Look Units			53XHL
363	C	PU= Press Units	230	55HM	56XLM
364	C	TS= “Tens”		61MS	
365	C	LT= Look Tens		62ML	35XHL
366	C	PT= Press Tens	200	64HM	65XLM
367	C	HS= “Hundreds”		66MS	
368	C	LH= Look Hundreds		67ML	17XHL
369	C	PH= Press Hundreds	300	69HM	70XLM
370	CW10?	RP= “Repeat”		**94MS**	
371	CX	Null Action	**333 <set**		
372	CW5?	US= “Units”			
373	CLU	LU= Look Units			53XHL
374	C	PU= Press Units	330	55HM	56XLM
375	C	TS= “Tens”		61MS	
376	C	LT= Look Tens		62ML	35XHL
377	C	PT= Press Tens	300	64HM	65XLM
378	C	HS= “Hundreds”		66MS	
379	C	LH= Look Hundreds		67ML	17XHL
380	C	PH= Press Hundreds	000	69HM	70XLM
381	CW10?	RP= “Repeat”		**95MS**	
382	CLH	LH= Look Hundreds	**013 <set**	**96ML**	0XHL
383	C	NO= “No”		1HS	2XLS
384	C	HS= “Hundreds”		3LS	4XHS
385	C	LT= Look Tens		59HL	17XHL
386	C	ON= “One”		21HS	22XLS
387	C	TN= “Ten”		23LS	8XHS
388	C	LU= Look Units		77HL	48XHL
389	C	TH= “Three”		52HS	46LS
390	C	US= “Units”		47LS	16XHS
391	C	LC= Close Eyes		84HL	53XHL
392	C	CF= Close Finger		81HM	75XLM
393	C	US= “Units”		86MS	
394	C	LU= Look Units		87ML	53XHL
395	C	PU= Press Units	010	55HM	56XLM
396	C	TS= “Tens”		61MS	
397	C	LT= Look Tens		62ML	35XHL
398	C	PT= Press Tens	020	64HM	65XLM
399	C	RP= “Repeat”		90MS	
400	CLH	LH= Look Hundreds		**97ML**	0XHL
401	C	NO= “No”		1HS	2XLS
402	C	HS= “Hundreds”			

Memory of action-predicting associations at step 402:

Format:

CA name: Context number: Events of context >> Associated event(s)

The associations are shown roughly in the order in which they are used during the task performance. Thus the second row associations overlap the first row associations. e.g.

58ML: PU, RP >> LH

1HS; RP, LH, 0 >> NO

```
ML:  58:PU,RP >> LH   97:PT,RP >> LH   96:PH,RP >> LH

HS:  1:RP,LH,0 >> NO  5:RP,LH,1 >> ON  9:RP,LH,2 >> TW 13:RP,LH,3 >> TH

LS:  3:LH,NO >> HS    7:LH,ON >> HD    11:LH,TW >> HS   15:LH,TH >> HS

HL:  59:NO,HS >> LT   76:ON,HD >> LT   78:TW,HS >> LT   82:TH,HS >> LT

HS:  18:HS,LT,0 >>NO  21:HS,LT,1 >>ON  24:HS,LT,2 >>TW 27:HS,LT,3 >>TH
HS:  31:HD,LT,0 >>NO  32:HD,LT,1 >>ON  33:HD,LT,2 >>TW  34:HD,LT,3 >>TH

LS:  20:LT,NO >> TS   23:LT,ON >> TN   26:LT,TW >> TS   29:LT,TH >> TS

HL:  60:NO,TS >> LU   77:ON,TN >> LU   79:TW,TS >> LU   83:TH,TS >> LT

HS:  36:TS,LU,0 >>NO  39:TS,LU,1 >>ON  42:TS,LU,2 >>TW  45:TS,LU,3 >>TH
HS:  49:TN,LU,0 >>NO  50:TN,LU,1 >>ON  51:TN,LU,2 >>TW  52:TN,LU,3 >>TH

LS:  38:LU,NO >> US   41:LU,ON >> UN   44:LU,TW >> US   47:LU,TH >> US

HL:  71:NO,US >> LC   72:ON,UN >> LC   80:TW,US >> LC   84:TH,US >> LC

HM:  81:US,LC >> CF   74:UN,LC >> CF

MS:  86:CF,= >> US

ML:  87:CF,US >> LU

HM:  55:US,LU >> PU

MS:  61:PU,0 >> TS    57:PU,1 >> RP    85:PU,2 >> RP    88:PU,3 >> RP

ML:  62:PU,TS >> LT
HM:  64:TS,LT >> PT

MS:  66:PT,0 >> HS    89:PT,1 >> RP    90:PT,2 >> RP    91:PT,3 >> RP

ML:  67:PT,HS >> LH

HM:  69:HS,LH >> PH

MS:  95:PH,0 >> RP    92:PH,1 >> RP    93:PH,2 >> RP    94:PH,3 >> RP

Disapproved associations:
ML:  62:PU,TS >> LU   67:PT,HS >> LT
HS:  54:US,LU,0 >> NO 63:TS,LT,0 >> NO   68:HS,LH,0 >> NO
LS:   20:LT,NO >> HS  23:LT,ON >> HD   26:LT,TW >> HS   29:LT,TH >> HS
LS:  38:LU,NO >> TS   41:LU,ON >> TN   44:LU,TW >> TS   47:LU,TH >> TS
HL:  71:NO,US >> LU   78:TW,HS >> LH

Extra associations:
XLM: 56:LU >> PU   65:LT >> PT    70:LH >> PH    75:LC >> CF
XHL: 0:RP >> LH    17:HS >> LH,LT   30:HD >> LT    35:TS >> LT,LU
XHL: 48:TN >> LU   53:US >> LC,LU   73:UN >> LC
XHS: 4:NO >>US,TS,HS  8:ON >>UN,TN,HD  12:TW >>US,TS,HS  16:TH >>US,TS,HS
XLS: 2:LH,0 >> NO     6:LH,1 >> ON     10:LH,2 >> TW    14:LH,3 >> TH
```

```
XLS: 19:LT,0 >> NO    22:LT,1 >> ON    25:LT,2 >> TW    28:LT,3 >> TH
XLS: 37:LU,0 >> NO    40:LU,1 >> ON    43:LU,2 >> TW    46:LU,3 >> TH
No extra associations are disapproved now.
```