

# **6502 Programming**

by Ted Kosan

Part of The Professor And Pat series  
( [professorandpat.org](http://professorandpat.org) )

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## 1 **Pat Returns From A Visit**

2 It had been almost a week since Pat had last stopped by. I was just  
3 beginning to wonder if Pat had decided that learning how to program a  
4 computer was too much effort when I heard a knock at my door. I opened  
5 the door and there stood Pat, wearing a big frown.

6 "Come in Pat." I said in a cheerful voice. "What are you so 'happy' about?"

7 "My family spent all last week visiting friends and I wasn't able to work with  
8 assembly language at all!" said Pat. "And when I told people that I was  
9 learning how a computer worked, they didn't seem to understand what I  
10 was talking about when I tried to explain it to them. I felt like I was alone in  
11 a strange way during this trip, even though I was surrounded by people. Do  
12 you kind of know what I mean, professor?"

13 I smiled and nodded my head. "Oh yes, I know what you mean, Pat. Most  
14 people that study technical subjects have this problem and the more you  
15 learn, the worse it gets."

16 After a few moments of thought I added "You could always stop learning  
17 about computers and perhaps devote your time to learning something more  
18 common, like a sport. This should give you plenty to talk about the next  
19 time you go visiting."

20 "No way!" said Pat with determination. "I'm never going to give up learning  
21 about computers! Ever since I started learning about computers, it feels  
22 like I've entered a whole new world which is full of wonder and unexpected  
23 possibilities. I haven't told you this before, but sometimes I get little pangs  
24 of fear about losing the knowledge of computers I have gained, like I  
25 learned it all in a dream and when I wake up, the knowledge will be gone. I  
26 wouldn't trade my knowledge of computers for anything in the world, not  
27 even for a cure for the loneliness I felt."

28 "As a technologist, you will indeed need to live with a certain amount of  
29 loneliness," I said "but only in certain situations like your visit.  
30 Fortunately, there are millions of people in the world who are deep  
31 technologists. They are very easy to communicate with through the  
32 Internet and they will understand exactly what you are talking about. Over  
33 time, you will find that the relationships you form with people on the  
34 Internet who have the same interests as you do will more than make up for  
35 the loneliness you experience in other areas of your life."

36 “Thanks, professor!” Pat said with a smile. “That lifted my spirits a bit.”

37 I smiled too as Pat's face brightened.

38 “Do you know what would make me feel even better, though?” asked Pat.

39 “What?” I asked.

40 “If you told me more about how programming worked.” replied Pat. “When  
41 I watch you create a program, you make it look so easy and I seem to  
42 understand most of what you are doing. By the time I get home, though, my  
43 understanding gets fuzzy and I become confused. That's why I want to talk  
44 more about programming and how to do it properly.

45 I understand how most of the instructions we have been using work, but I  
46 don't quite get how to arrange the instructions into sequences that can  
47 solve problems. It seems to me that a lot part of programming exists at a  
48 level that is above the instructions themselves, but I just can't see it yet.”

## 49 Algorithms

50 “You are correct about a significant part of programming existing at a level  
51 that is above the level of the instructions, Pat.” I said. “A computer  
52 programmer certainly needs to know at least one programming language,  
53 but when a programmer solves a problem, they do it at a level that is higher  
54 in abstraction than even the more abstract computer languages.

55 After the problem is solved, then the solution is encoded into a  
56 programming language. It is almost as if a programmer is actually two  
57 people. The first person is the **problem solver** and the second person is  
58 the **coder**. The reason that programming may seem confusing to you is  
59 that, when you have watched me program you have only seen the coding  
60 phase and not the problem solving phase which I have been doing in my  
61 head.

62 I have been doing the problem solving phase in my head because the  
63 programs we have developed up to this point have been simple. With more  
64 complex programs, however, the problem solving phase and the coding  
65 phase are more distinct. The solution to a problem is usually recorded and  
66 then passed from the **problem solver** to the **coder** in the form of a  
67 document.”

68 “Are you saying that the problem solver can solve a programming problem  
69 without even turning on the computer?” asked Pat.

70 “Yes.” I replied “The first thing that a problem solver will do with a problem  
71 is to **analyze** it. This is an extremely important step because if a problem is  
72 not analyzed, then it can not be properly solved.”

73 “What does analyze mean?” asked Pat.

74 “To **analyze** something means to break it down into its component parts  
75 and then these parts are studied to determine how they work.” I replied. “A  
76 well known saying is '**divide and conquer**' and when a difficult problem is  
77 analyzed, it is broken down into smaller problems which are each simpler to  
78 solve than the overall problem. The **problem solver** then develops an  
79 **algorithm** to solve each of the simpler problems and, when these  
80 algorithms are combined, they form the solution to the overall problem.”

81 “An algo-what?” asked Pat.

82 “An al-gor-rhythm.” I said. “An **algorithm** is a sequence of instructions  
83 which describe how to accomplish a given task. These instructions can be  
84 expressed in various ways including writing them in natural languages ( like  
85 English ), drawing diagrams of them, and encoding them in a programming  
86 language.

87 The concept of an algorithm came from the various procedures that  
88 mathematicians developed for solving mathematical problems, like  
89 calculating the sum of 2 numbers or calculating their product.

90 Algorithms can also be used to solve more general problems. An example  
91 would be the set of instructions that could be followed by a person who  
92 needs to solve the garage sizing problem we discussed earlier.” I then  
93 wrote the following algorithm on the whiteboard:

94 1) Measure the length and width of each item that will be placed into the  
95 garage using metric units and record these measurements.

96 2) Divide the measurements from step 1 by 100 then cut out pieces of paper  
97 that match these dimensions to serve as models of the original items.

98 3) Cut out a piece of paper which is 1.5 times as long as the model of the  
99 largest car and 3 times wider than it to serve as a model of the garage floor.

100 4) Locate where the garage doors will be placed on the model of the garage  
101 floor, mark the locations with a pencil, and place the models of both cars on  
102 top of the model of the garage floor, just within the perimeter of the paper  
103 and between the two pencil marks.

104 5) Place the models of the items on top of the model of the garage floor in  
105 the empty space that is not being occupied by the models of the cars.

106 6) Move the models of the items into various positions within this empty  
107 space to determine how well all the items will fit within this size garage.

108 7) If the fit is acceptable, go to step 10.

109 8) If there is not enough room in the garage, increase the length dimension,  
110 the width dimension ( or both dimensions ) of the garage floor model by 10%,  
111 create a new garage floor model, and go to step 4.

112 9) If there is too much room in the garage, decrease the length dimension,  
113 the width dimension ( or both dimensions ) of the garage model by 10%, create  
114 a new garage floor model, and go to step 4.

115 10) Measure the length and width dimensions of the garage floor model,  
116 multiply these dimensions by 100, and then build the garage using these  
117 larger dimensions.

118 "That's a lot of steps!" said Pat.

119 "Yes," I said "an algorithm needs to be detailed enough so that it leads to  
120 the desired solution if it is followed exactly. This often results in an  
121 algorithm having a significant number of steps. After the steps have been  
122 developed and recorded in a document, however, they can be followed over  
123 and over again by people who need to solve the given problem."

124 "This algorithm for the garage sizing problem is written in English  
125 sentences." said Pat. "Are algorithms usually written using sentences  
126 before being encoded into programs, or can they be encoded into a  
127 programming language right from the start?"

128 "An algorithm is usually not expressed in a programming language while it  
129 is being developed and this is why a computer does not need to be turned  
130 on during algorithm development. After the algorithm is complete and  
131 recorded in a document, it is then encoded into a programming language as  
132 a separate step."

133 "What happens if the program that the algorithm was encoded into doesn't  
134 run correctly when it is executed?" asked Pat.

135 "Assuming that the **syntax** of the program is correct," I replied "the

136 problem will usually be 1) an incorrect algorithm that was encoded  
137 correctly, 2) a correct algorithm that was encoded incorrectly, or 3) an  
138 incorrect algorithm that was encoded incorrectly. The programmer needs  
139 to study both the algorithm and the way it was encoded into a program in  
140 order to find the cause of the problem.

141 When either syntax errors or algorithm errors are present in a program, the  
142 program is said to have '**bugs**' and the process of locating the bugs and  
143 fixing them is known as **debugging** the program."

144 "Bugs can't get inside of computer chips so why are program errors called  
145 bugs!?" asked Pat.

146 I smiled and said "Bugs can not crawl inside of today's computer chips, but  
147 the early computers used larger electrical components that bugs could  
148 crawl into." I then found the following information on the Internet which  
149 explained where the concept of a computer bug came from:

150 Date: 23 Aug 1981 05:38:25-PDT  
151 From: ARPAVAX.sjk at Berkeley  
152 Subject: origin of bug

153 Ever wondered about the origins of the term "bugs" as applied to computer  
154 technology? U.S. Navy Capt. Grace Murray Hopper has firsthand explanation.  
155 The 74-year-old captain, who is still on active duty, was a pioneer in  
156 computer technology during World War II. At the C.W. Post Center of  
157 Long Island University, Hopper told a group of Long Island public school  
158 administrators that the first computer "bug" was a real bug -- a moth.  
159 At Harvard one August night in 1945, Hopper and her associates were working  
160 on the "granddaddy" of modern computers, the Mark I. "Things were going  
161 badly; there was something wrong in one of the circuits of the long  
162 glass-enclosed computer," she said. "Finally, someone located the  
163 trouble spot and, using ordinary tweezers, removed the problem, a two-inch  
164 moth. From then on, when anything went wrong with a computer, we said it  
165 had bugs in it." Hopper said that when the veracity of her story was  
166 questioned recently, "I referred them to my 1945 log book, now in the  
167 collection of Naval Surface Weapons Center, and they found the remains of  
168 that moth taped to the page in question."

9/9

0800 Antan started  
 1000 stopped - antan ✓ { 1.2700 9.037 847 025  
 1300 (032) MP-MC 1.98264000 9.037 846 995 correct  
 (033) PRO 2 2.130476415 (03) 4.615925059(-2)  
 correct 2.130476415  
 Relays 6-2 in 033 failed special speed test  
 in relay 11.000 test.  
 (Relays changed)  
 1100 Started Cosine Tapc (Sine check)  
 1525 Started Mult+ Adder Test.  
 1545 Relay #70 Panel F  
 (moth) in relay.  
 First actual case of bug being found.  
 1630 Antan started.  
 1700 closed down.

Relay 2745  
 Relay 337

169 "That's hilarious!" said Pat.

## 170 Computation

171 After a few moments of thought Pat said "I understand how a person can  
 172 perform the steps in an algorithm, Professor, but I am having a hard time  
 173 understanding how a computer can perform these steps when its CPU is  
 174 only capable of executing simple machine language instructions."

175 "In order to understand how a CPU is able to perform the steps in an  
 176 algorithm, one must first understand what **computation** ( which is also  
 177 known as **calculation** ) is." I said. "Lets search for some good definitions of  
 178 each of these words on the Internet and read what they have to say." I then  
 179 performed the search and selected the following 2 definitions for  
 180 **computation**:

181 1) The manipulation of numbers or symbols according to fixed rules. Usually  
 182 applied to the operations of an automatic electronic computer, but by  
 183 extension to some processes performed by minds or brains.  
 184 ( [www.informatics.susx.ac.uk/books/computers-and-thought/gloss/node1.html](http://www.informatics.susx.ac.uk/books/computers-and-thought/gloss/node1.html) )

185 2) A computation can be seen as a purely physical phenomenon occurring inside  
 186 a closed physical system called a computer. Examples of such physical systems  
 187 include digital computers, quantum computers, DNA computers, molecular  
 188 computers, analog computers or wetware computers.



189 ( [www.informatics.susx.ac.uk/books/computers-and-thought/gloss/node1.html](http://www.informatics.susx.ac.uk/books/computers-and-thought/gloss/node1.html) )

190 I had Pat read the definitions for computation out loud then I said “The 2  
191 definitions for **computation** I selected indicate that it is the '**manipulation**  
192 **of numbers or symbols according to fixed rules**' and that it '**can be**  
193 **seen as a purely physical phenomenon occurring inside a closed**  
194 **physical system called a computer.**' Both definitions indicate that the  
195 machines we normally think of as computers are just **one type of**  
196 **computer** and that other types of closed physical systems can also act as  
197 computers. These other types of computers include DNA computers,  
198 molecular computers, analog computers, and wetware computers ( or  
199 brains ).”

200 “Are you saying that brains manipulate symbols using rules, just like normal  
201 computers do?” asked Pat.

202 “Yes.” I replied.

203 “How can brains manipulate symbols?” asked Pat. “Do they implement the  
204 Von Neumann architecture?”

205 “No,” I replied “brains do not implement the Von Neumann architecture,  
206 but they do manipulate symbols using rules just like normal computers do.  
207 Read aloud the 2 definitions for **calculation** I selected and lets see if these  
208 definitions shed any light on the kind of rules that normal computers,  
209 brains, and other types of computers use.” Pat then read the following  
210 definitions:

211 1) A calculation is a deliberate process for transforming one or more inputs  
212 into one or more results. ( [en.wikipedia.org/wiki/Calculation](http://en.wikipedia.org/wiki/Calculation) )

213 2) Calculation: the procedure of calculating; determining something by  
214 mathematical or logical methods ( [wordnet.princeton.edu/perl/webwn](http://wordnet.princeton.edu/perl/webwn) )

215 “These definitions for calculation,” I said “indicate that it '**is a deliberate**  
216 **process for transforming one or more inputs into one or more**  
217 **results**' and that this is done '**by mathematical or logical methods**'. We  
218 do not yet completely understand what mathematical and logical methods  
219 brains use to perform calculations, but rapid progress is being made in this  
220 area.”

221 “What is logic?” asked Pat.

222 “The concept of logic is used in a number of different contexts. I will find a  
223 definition for **logic** on the Internet which fits our context.” I then located  
224 the following definition and had Pat read it aloud:

225 The logic of a system is the whole structure of rules that must be used for  
226 any reasoning within that system. Most of mathematics is based upon a well-  
227 understood structure of rules and is considered to be highly logical. It is  
228 always necessary to state, or otherwise have it understood, what rules are  
229 being used before any logic can be applied. ( ddi.cs.uni-  
230 potsdam.de/Lehre/TuringLectures/MathNotions.htm )

231 “**Reasoning**,” I said “is the process of using predefined rules to move from  
232 one point in a system to another point in the system. For example, when a  
233 person adds 2 numbers together on a piece of paper, they must follow the  
234 rules of the addition algorithm in order to obtain a correct sum. The  
235 addition algorithm's rules are its logic and, when someone applies these  
236 rules during a calculation, they are **reasoning** with the rules.

237 Lets now apply these concepts to your question about how a computer can  
238 perform the steps of an algorithm when its CPU is only capable of executing  
239 simple machine language instructions. When a person develops an  
240 algorithm, the steps in the algorithm are usually stated as high-level tasks  
241 which do not contain all of the smaller steps that are necessary to perform  
242 each task.

243 For example, a person might write a step that states 'Drive from New York  
244 to San Francisco.' This large step can be broken down into smaller steps  
245 that contain instructions such as 'turn left at the intersection, go west for 10  
246 kilometers, etc.' If all of the smaller steps in a larger step are completed,  
247 then the larger step is completed too.

248 A human that needs to perform this large driving step would usually be able  
249 to figure out what smaller steps need to be performed in order accomplish  
250 it. As we learned earlier, however, computers are very stupid and before  
251 any algorithm can be executed on a computer, the algorithm's steps must be  
252 broken down into smaller steps, and these smaller steps must be broken  
253 down into even small steps, until the steps are simple enough to be  
254 performed by the instruction set of a CPU.”

255 “How many smaller steps does a larger step usually need to be broken down  
256 into before it can be implemented in machine language?” asked Pat.

257 “Sometimes only a few smaller steps are needed to implement a larger step,

258 but sometimes hundreds or even thousands of smaller steps are required.  
259 Hundreds or thousands of smaller steps will translate into hundreds or  
260 thousands of machine language instructions.”

261 “That's a lot of steps and instructions!” said Pat. “It almost seems like its  
262 too much work to convert an algorithm into thousands of little steps and  
263 then into maybe thousands of assembly language instructions needed to run  
264 it on a computer.”

265 “You are right, Pat.” I said “If assembly language was the only language  
266 that computers could be programmed in, then most algorithms would be too  
267 large to be placed into a computer. It was for the purpose of solving this  
268 problem that high-level languages were created.

269 With assembly language, a human needs to manually convert an algorithm  
270 into assembly language instructions before a computer can execute the  
271 algorithm. An algorithm that is encoded into a high-level language,  
272 however, does not need to be broken down into as many smaller steps as  
273 would be needed with assembly language. The hard work of breaking down  
274 an algorithm that has been encoded into a high-level language is  
275 automatically done by either a **compiler** or an **interpreter**. This is why  
276 most of the time, programmers use a high-level language to develop in  
277 instead of assembly language.”

278 “If high-level languages are so much easier to encode algorithms into than  
279 assembly language,” said Pat “why are we studying assembly language?”

280 I smiled, looked at Pat, and said “For many years, I taught beginning  
281 programming to students using the normal method of starting them with a  
282 high-level language without covering assembly language at all. A beginning  
283 programmer is definitely able to start writing programs quicker in a high-  
284 level language than they could with assembly language and I ( along with  
285 many others ) thought that quicker in this case meant better.

286 Over time, however, I noticed that most of these students were not able to  
287 program very well. I eventually figured out that the main reason that most  
288 of them could not program very well was that they did not understand how  
289 a computer actually worked because much of this understanding is at the  
290 assembly language level.

291 Even though most programmers do not program in assembly language,  
292 somehow, having a solid understanding of how a computer works at its

293 lowest levels, and having had the experience of manually encoding  
294 algorithms into assembly language, wires a programmer's brain in a way  
295 that enables them to be much better high-level language programmers than  
296 they otherwise would be.

297 I love assembly language, but even I prefer to program in a high-level  
298 language whenever possible. The reason I am teaching assembly language  
299 to you as your first computer language is because I want to give you the  
300 foundation you will need to become an excellent high-level language  
301 programmer."

## 302 UML Activity Diagrams

303 Pat said "I think I'm beginning to understand now how a programmer  
304 becomes a **problem solver** when they develop an algorithm and then  
305 becomes a **coder** when they encode the algorithm into a programming  
306 language. I would like to talk some more about how the problem solver  
307 develops an algorithm, though.

308 Earlier you said that an algorithm can be recorded in a natural language  
309 like English but it can also be recorded using a diagram. Can you show me  
310 how recording an algorithm into a diagram would work?"

311 "Yes." I replied. "You may be surprised to learn, however, that a whole  
312 diagram-based language has been created which allows all aspects of a  
313 program to be designed by 'problem solvers', including the algorithms that  
314 a program uses. This language is call **UML** which stands for **Unified**  
315 **Modeling Language**. Later on, when we begin studying high-level  
316 languages, we will cover UML in more depth. For now, though, I will show  
317 you how one of UML's diagrams, called an **Activity diagram**, works.

318 The purpose of an **Activity diagram** is to show the sequence of steps ( or  
319 activities ) that are part of some piece of logic and this makes them well  
320 suited for recording algorithms. I will now show you how activity diagrams  
321 work by using them to develop algorithms which solve various problems. I  
322 will also encode each diagram into a 6502 assembly language program so  
323 you can see how the encoding process is done."

## 324 Calculating The Sum Of The Numbers Between 1 And 10

325 Before I began solving the first problem, I took some sheets of paper from  
326 the printer and created 2 funny-looking hats with them using a scissors and  
327 tape. I wrote 'Problem Solver' on the first hat and 'Coder' on the second hat

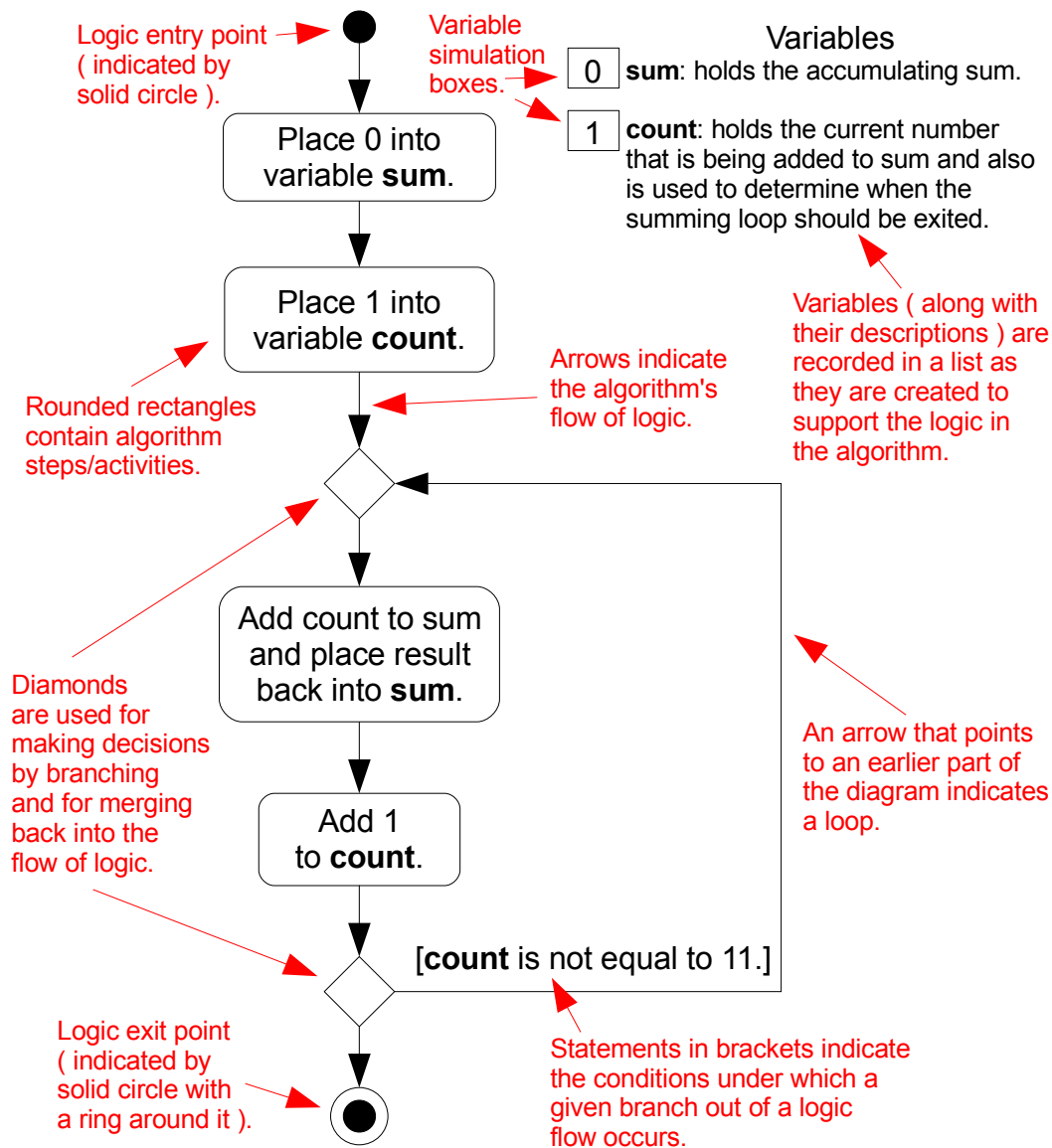
328 and Pat started laughing when I put on the 'Problem Solver' hat.

329 “The first thing that needs to be done with a problem before it can be  
330 analyzed and solved,” I said “is to describe it clearly and accurately.” I then  
331 wrote the following problem description on the whiteboard:

332 **Description:** In this problem, the sum of the numbers between 1 and 10  
333 inclusive needs to be determined.

334 “Inclusive here means that the numbers 1 and 10 will be included in the  
335 sum.” I said. “Since this is a fairly simple problem that is similar to one I  
336 solved earlier with a program, we will not need to spend too much time  
337 analyzing it.” I then developed an algorithm for solving the problem by  
338 drawing an Activity diagram on the whiteboard. (see Fig. 1)

Figure 1



339 As I was developing the Activity diagram, I created variables as needed and  
 340 recorded their names in a list along with their descriptions. I would also  
 341 periodically start at the entry point and walk through the logic to make sure  
 342 it was correct ( I did this out loud so Pat could follow along too ). I placed  
 343 simulation boxes next to each variable so that I could record and update  
 344 how the logic was changing the variable's values. During a walk-through, I  
 345 would often find errors which I would then fix by moving flow arrows and  
 346 adjusting the text that was inside the activity rectangles.

347 Eventually, I reached a point where I could not find any more errors in the

348 logic and then I said to Pat “It looks like the algorithm is complete now and  
 349 I can stop being the **problem solver** and pass the algorithm over to the  
 350 **coder** so it can be encoded into assembly language.” I then took off the  
 351 'Problem Solver' hat and put on the 'Coder' hat and Pat started laughing  
 352 again. I brought up an editor and encoded the Activity diagram into the  
 353 following 6502 assembly language program:

```

354          000001 |;Program Name: sum10.
355          000002 |;
356          000003 |;Version: 1.02
357          000004 |;
358          000005 |;Description: In this program, the sum of the
359          000006 |; numbers between 1 and 10 inclusive will be
360          000007 |; determined.
361          000008 |
362          000009 |;*****
363          000010 |;Program entry point.
364 0200      000011 |      org 0200h
365          000012 |
366          000013 |;Place 0 into variable sum.
367 0200 A9 00  000014 |      lda #0d
368 0202 8D 1F 02 000015 |      sta sum
369          000016 |
370          000017 |;Place 1 into variable count.
371 0205 A9 01  000018 |      lda #1d
372 0207 8D 20 02 000019 |      sta count
373          000020 |
374          000021 |;Top of summing loop.
375 020A      000022 |LoopTop *
376          000023 |
377          000024 |;Add count to sum and place result back into sum.
378 020A AD 1F 02 000025 |      lda sum
379 020D 18      000026 |      clc
380 020E 6D 20 02 000027 |      adc count
381 0211 8D 1F 02 000028 |      sta sum
382          000029 |
383          000030 |;Add 1 to count.
384 0214 EE 20 02 000031 |      inc count
385          000032 |
386          000033 |;If count is not equal to 11 yet then branch back
387          000034 |; to LoopTop.
388 0217 AD 20 02 000035 |      lda count
389 021A C9 0B  000036 |      cmp #11d
390 021C D0 EC  000037 |      bne looptop
391          000038 |
392          000039 |;Exit program.
393 021E 00      000040 |      brk
394          000041 |
395          000042 |;*****
396          000043 |;Variables area.
397          000044 |
398          000045 |;Holds the accumulating sum.
399 021F 00      000046 |sum    dbt 0d

```

```
400          000047 |
401          000048 |;Holds the current number
402          000049 |; that is being added to sum and also
403          000050 |; is used to determine when the summing
404          000051 |; loop should be exited.
405 0220 00      000052 |count          dbt 0d
406          000053 |
407          000054 |          end
```

408 It did not take me very long to develop the program and when I was finished  
409 I took off the Coder hat.

410 Pat said “That was fast. In fact, it took you much longer to develop the  
411 algorithm than it did to code the program. Is that normal?”

412 “Yes,” I replied “most of the work that is involved in developing a program  
413 happens in the **problem solving** stage. After the program's logic has been  
414 developed and recorded in a document like an Activity diagram, coding this  
415 logic is usually a straight-forward task.

416 I now want you to study both the Activity diagram and the program and  
417 then tell me if you notice anything interesting about the comments in the  
418 program.

419 Pat studied both the diagram and the program for a while then said “Hey,  
420 the comments in the program are taken directly from the diagram!”

421 “Indeed they are.” I said. “You wanted to see how the steps in an algorithm  
422 were encoded into assembly language and you can see in this example that  
423 the encoding process consists of taking each step in the algorithm and  
424 creating a group of assembly language instructions that perform that step.  
425 All the assembly language instructions in a given group are the small steps  
426 that need to be performed in order to perform the larger step they are a  
427 part of.

428 The task of translating a step in the algorithm to a group of assembly  
429 language instructions that represent that step in a program is so direct that  
430 the text that describes the step in the algorithm can often be used  
431 unchanged to describe what its analogous group of instructions does.”

## 432 **Finding The Largest Number In A List Of 100 Numbers**

433 “Here is the next problem we are going to solve,” I said. I then wrote this



434 problem description on the whiteboard:

435 Description: Find the largest number in a list of 100 numbers.

436 “This problem is more sophisticated than the previous problem and so we  
437 will need to spend more time analyzing it.” I said. “One of the strategies for  
438 solving any problem is to **try to solve a simpler problem that is similar**  
439 **to the original problem**. In this case, I propose that we try to solve the  
440 problem for a list of 5 numbers first, then use the knowledge we gained to  
441 solve the larger problem.”

442 “Okay.” Said Pat.

443 “What should the **range** be for the numbers in the list?” I asked.

444 “Range?” asked Pat.

445 “**Range** in this case means the numbers in the list can be no lower than a  
446 certain number and no higher than some other number. Therefore, you  
447 have a range of numbers between a lower limit number and an upper limit  
448 number to choose from.” I said.

449 “Will the lower limit number and the upper limit number both be inclusive?”  
450 asked Pat?

451 “Yes they will.” I replied. “Also, when a person is developing an algorithm  
452 that will be encoded into a programming language, they must **always be**  
453 **mindful of how many bits will be needed to represent the numbers in**  
454 **the algorithm**. In this case, I recommend that we use **bytes** to represent  
455 the numbers in the list and that the numbers be non-negative. With these  
456 assumptions, what is the range of the numbers that can be in the list?”

457 “0 to 255.” said Pat.

458 “Very good.” I said. “Whenever assumptions are applied to an algorithm,  
459 these should be recorded near the problem's description.” I then added the  
460 following assumption section to the whiteboard:

461 Assumptions: The numbers in the list will be no lower than 0 and no higher  
462 than 255.

463 “Now, give me a list of 5 numbers that meet these requirements.” I said.

464 Pat thought for a moment then said "172, 34, 3, 242, 99."  
465 I wrote these numbers on the whiteboard.  
466 "What variables do you think our algorithm is going to need?" I asked.  
467 Pat said "I think we are going to need a variable to hold the **largest**  
468 number. Hmm, I am not sure what other variables we will need, though."  
469 "How should we keep track of where we are in the list?" I asked.  
470 "Oh yes, we will also need an **indexing** variable." said Pat.  
471 "Lets start with these variables, then, and begin developing the program's  
472 logic." I said. Then I put the information on the whiteboard (see Fig. 2)

Figure 2



[172, 34, 3, 242, 99]

Variables

**largest** - Holds the largest number encountered so far in the list.**index** - Points to the number in the list that the algorithm is currently working with.

473 "What should the algorithm do first, Pat?" I asked.  
474 Pat studied the information I had placed on the whiteboard then said "I  
475 think the first thing the algorithm should do is to set the variables to their  
476 initial values."  
477 "I agree." I said. "Setting variables to their initial values is referred to as  
478 **initializing** the variables and they can be initialized either by algorithm  
479 steps or by just placing the initial values into the variable's simulation  
480 boxes. If the initial values are placed into the simulation boxes, these  
481 variables will be initialized when the variables are defined in the program.  
482 For example, in the 6502 assembly language we have been using, **largest**  
483 **dbt 5d** would initialize the variable **largest** to 5 decimal. Since we  
484 initialized the variables using logic in the last problem, we will initialize  
485 them when they are defined in this problem."  
486 "Okay." said Pat.

487 “What should we initialize these variables to?” I asked.

488 “The variable **index** should be initialized to 0 but I'm not sure what **largest**  
489 should be initialized to.” said Pat after thinking about the question for some  
490 time.

491 “If you are not sure, just come up with a number for now and we will  
492 change it if we find a better number later.

493 “Set it to 75.” said Pat. I then set **largest** to 75 and **index** to 0.

494 “Now pretend that you are a computer and describe how you would  
495 determine the largest number in this list.” I said. “Keep in mind that the  
496 computer is not able to 'see' the whole list at one time like a human can.  
497 The computer is only able to see 1 number in the list at any given time so  
498 which number would you start with?”

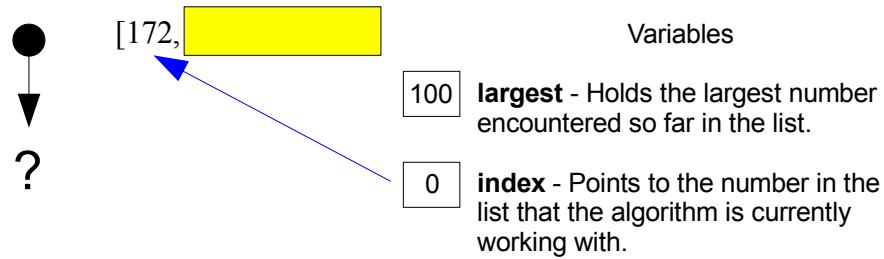
499 “I would probably start with the first number in the list.” answered Pat.

500 “Which number is the first number in the list and what offset is it at?” I  
501 asked.

502 “172 is the first number and it is at offset 0.” replied Pat.

503 I then covered the other numbers in the list with a yellow piece of paper  
504 and drew an arrow from **index's** simulation box to the number 172. (see  
505 Fig. 3)

Figure 3

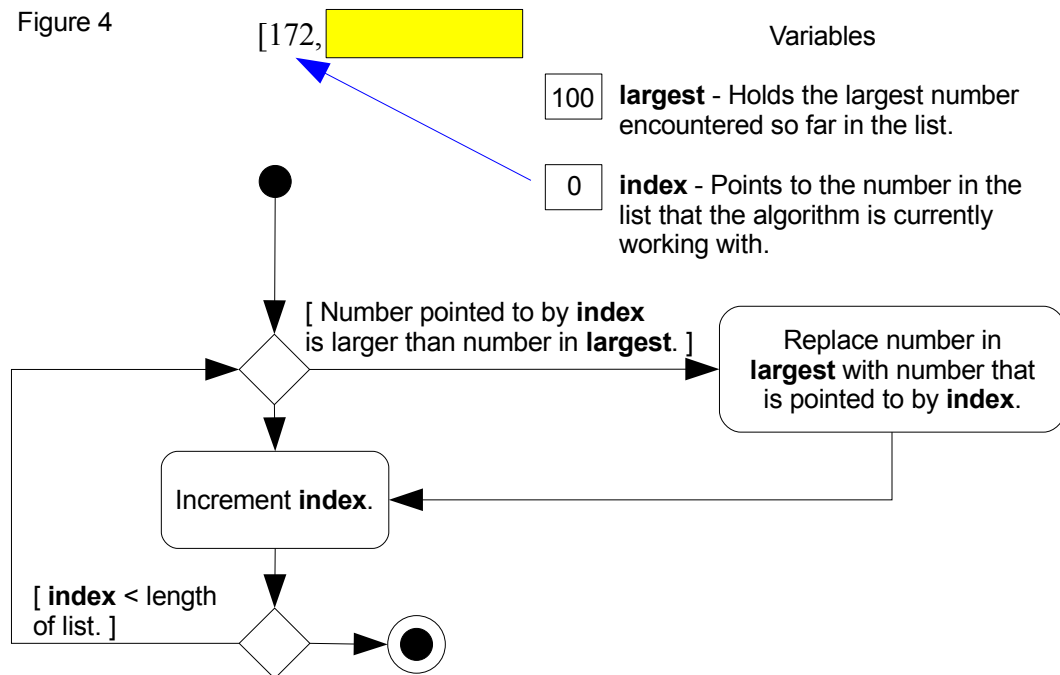


506 Then I said "What logic do you think should be performed in the algorithm,  
 507 Pat?"

508 "How about something like '**If** the number referenced by **index** is greater  
 509 than the number that is in **largest**, **then** replace the number in **largest**  
 510 with the number that is referenced by **index**. Increment **index** to point to  
 511 **each number in the list in turn** so that the logic can determine if it is the  
 512 largest so far.'" said Pat.

513 "That sounds pretty good!" I said. "Now lets place this logic into the  
 514 Activity diagram. Whenever you encounter '**if**' and '**then**' inside sentences  
 515 that describe logic, these words indicate that a **decision** is being made. In  
 516 this case, we will place a **diamond** immediately after the **entry point**  
 517 **symbol** in the Activity diagram and then attach an **activity rectangle** that  
 518 contains the 'number compare and replace logic' to it. The words '**in turn**'  
 519 indicate that a loop will be needed in the algorithm." I then added this logic  
 520 to the Activity diagram. (see Fig. 4)

Figure 4



521 When the Activity diagram was finished I said “Our next step is to pretend  
522 we are a computer and perform a **dry run** of the logic in the algorithm.”

523 “A dry run?” asked Pat “What does that mean?”

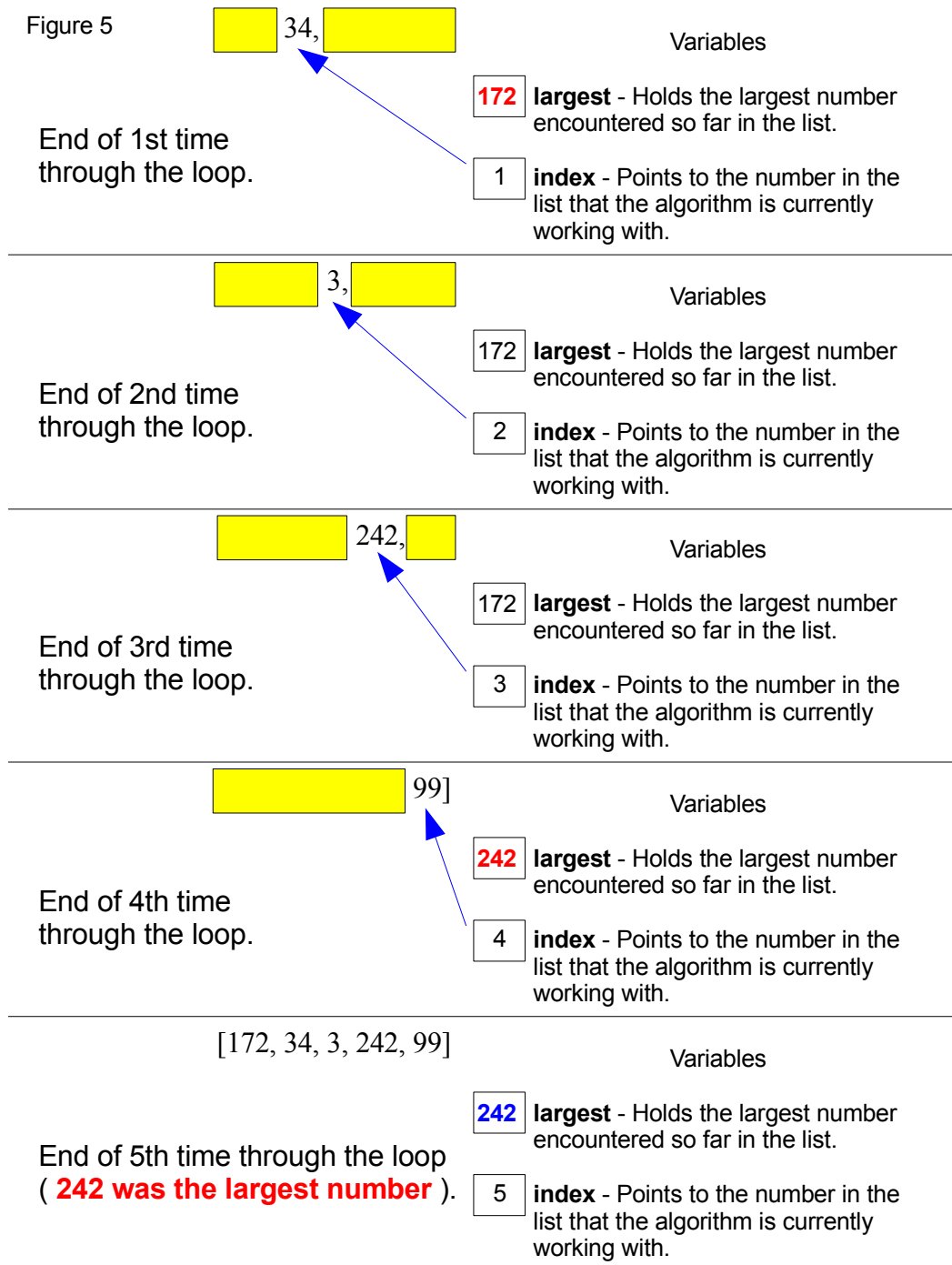
524 “In the context of computer programming,” I replied “it means to mentally  
525 execute a program, or a program's algorithms, without using a computer. A  
526 programmer should always dry run their algorithms and programs to make  
527 sure they are correct.”

528 “Why are dry runs 'dry'?” asked Pat.

529 I laughed and said “My understanding is that the term **dry run** comes from  
530 the firefighter service. When a firetruck is sent out on a rehearsal or test  
531 run, water is not usually used and therefore the run is dry. The term dry  
532 run is often used to mean any kind of a rehearsal or test that is performed  
533 before doing it for real.”

534 Pat and I then did a dry run of the algorithm using the list of numbers that  
535 Pat came up with which were 172, 34, 3, 242, and 99. (see Fig. 5)

Figure 5



536 "It worked!" cried Pat. "The algorithm figured out that the largest number  
537 in the list is 242!"

538 "Yes it did, but we can not celebrate just yet." I said.

539 "Why not?" asked Pat.

540 "Dry run the algorithm again, but this time use this list of numbers."

541 I wrote the following list on the whiteboard:

542 {2, 9, 3, 5, 7}

543 Pat performed another dry run of the algorithm with the second list then  
544 said "Hey, it didn't work this time! The algorithm says that the largest  
545 number in the list is 75 even though the largest number is actually 9."

546 "What do you think the problem is?" I asked.

547 Pat studied the algorithm for a while then said "Oh, I see the problem. I  
548 had told you to initialize the variable **largest** to 75, but 75 is larger than all  
549 of the numbers in the second list. Since none of the numbers in the list is  
550 larger than 75, the 75 never gets replaced."

551 "Is there a number we can initialize **largest** to so that the algorithm will  
552 work correctly with any list that conforms to our stated assumptions?" I  
553 asked.

554 Pat thought about this question for a while then said "I think we will need to  
555 initialize **largest** with the lowest number in the range of numbers that are  
556 allowed to be in the list. Since 0 is the lowest number in the range we  
557 selected, this is what we should initialize largest to."

558 "Very Good!" I said. "These are the type of errors that performing dry runs  
559 of algorithms and programs are meant to find. I think our algorithm is  
560 correct now and it should also be able to handle the 100 number list from  
561 the original problem. I will now encode the algorithm into a program." I  
562 brought up an editor and encoded the logic that was in the Activity diagram  
563 into the following program:

```
564          000001 |;Program Name: largest.  
565          000002 |;  
566          000003 |;Version: 1.0.
```

```

567      000004 |;
568      000005 |;Description: Find the largest number in a list
569      000006 |; of 100 numbers.
570      000007 |;
571      000008 |;Assumptions: The numbers in the list will be no
572      000009 |; lower than 0 and no higher than 255.
573      000010 |
574      000011 |
575      000012 |;*****
576      000013 |;Program entry point.
577 0200      000014 |      org 0200h
578      000015 |
579      000016 |;This program will use the X register to point
580      000017 |; to the current number in the list
581      000018 |; instead of a variable called 'index'.
582      000019 |;
583      000020 |;Initialize register X to refer to offset 0 into
584      000021 |; the list of numbers starting at 'list'.
585 0200 A2 00      000022 |      ldx #0d
586      000023 |
587      000024 |;Compare the number that X is referring to in the
588      000025 |; list to the number that is in 'largest'. If the
589      000026 |; number being pointed to is larger than the contents
590      000027 |; of the variable 'largest', then fall through to
591      000028 |; the code that will replace the contents of 'largest'
592      000029 |; with the new number.
593 0202      000030 |LoopTop *
594 0202 BD 14 02      000031 |      lda list,x
595 0205 CD 13 02      000032 |      cmp largest
596 0208 90 03      000033 |      bcc NotLarger
597      000034 |
598 020A      000035 |IsLarger *
599      000036 |
600      000037 |;Replace the number in 'largest' with the current
601      000038 |; number from the list.
602 020A 8D 13 02      000039 |      sta largest
603      000040 |
604 020D      000041 |NotLarger *
605      000042 |
606      000043 |;Increment the X register so that it references the
607      000044 |; next number in the list.
608 020D E8      000045 |      inx
609      000046 |
610      000047 |;Check to see if the end of the list has been reached.
611      000048 |; If it has, then exit the program. If it has not,
612      000049 |; then branch back to the top of the loop.
613 020E      000050 |CheckListEnd *
614 020E E0 64      000051 |      cpx #100d
615 0210 D0 F0      000052 |      bne LoopTop
616      000053 |
617      000054 |;Exit the program.
618 0212 00      000055 |      brk
619      000056 |
620      000057 |
621      000058 |;*****
622      000059 |;Variables area.

```



```

623      000060 |;
624      000061 |;In this program, the variables area is being placed
625      000062 |; below the code because the variables take up
626      000063 |; a significant amount of memory. This makes
627      000064 |; it more difficult to determine where the variables
628      000065 |; area ends so that the start of the code area
629      000066 |; can be determined.
630      000067 |
631      000068 |
632      000069 |;Holds the largest number
633      000070 |; encountered so far in the list.
634      000071 |; ( Notice that variables can
635      000072 |; be initialized here instead of
636      000073 |; in the code as an option ).
637      0213 00      000074 |largest dbt 0d
638      000075 |
639      000076 |
640      000077 |;This list contains 100 numbers ranging from 0
641      000078 |; to 255.
642      0214 3B      000079 |list dbt 59d,61d,37d,128d,71d,150d,195d,130d,69d,84d
643      0215 3D
644      0216 25
645      0217 80
646      0218 47
647      0219 96
648      021A C3
649      021B 82
650      021C 45
651      021D 54
652      021E AB      000080 | dbt 171d,227d,99d,214d,233d,136d,80d,253d,242d
653      021F E3
654      0220 63
655      0221 D6
656      0222 E9
657      0223 88
658      0224 50
659      0225 FD
660      0226 F2
661      0227 70      000081 | dbt 112d,221d,151d,101d,117d,76d,226d,174d,205d
662      0228 DD
663      0229 97
664      022A 65
665      022B 75
666      022C 4C
667      022D E2
668      022E AE
669      022F CD
670      0230 54      000082 | dbt
671      84d,78d,139d,89d,195d,243d,69d,128d,217d,215d
672      0231 4E
673      0232 8B
674      0233 59
675      0234 C3
676      0235 F3
677      0236 45
678      0237 80

```

679	0238	D9		
680	0239	D7		
681	023A	39	000083	dbt 57d,100d,227d,226d,233d,238d,229d,228d,135d
682	023B	64		
683	023C	E3		
684	023D	E2		
685	023E	E9		
686	023F	EE		
687	0240	E5		
688	0241	E4		
689	0242	87		
690	0243	8C	000084	dbt 140d,98d,211d,245d,120d,206d,198d,47d,191d
691	0244	62		
692	0245	D3		
693	0246	F5		
694	0247	78		
695	0248	CE		
696	0249	C6		
697	024A	2F		
698	024B	BF		
699	024C	EF	000085	dbt 239d,27d,236d,12d,242d,148d,98d,11d,38d,189d
700	024D	1B		
701	024E	EC		
702	024F	0C		
703	0250	F2		
704	0251	94		
705	0252	62		
706	0253	0B		
707	0254	26		
708	0255	BD		
709	0256	EE	000086	dbt 238d,225d,142d,214d,214d,21d,75d,17d,190d
710	0257	E1		
711	0258	8E		
712	0259	D6		
713	025A	D6		
714	025B	15		
715	025C	4B		
716	025D	11		
717	025E	BE		
718	025F	B2	000087	dbt 178d,123d,125d,123d,10d,166d,123d,135d,220d
719	0260	7B		
720	0261	7D		
721	0262	7B		
722	0263	0A		
723	0264	A6		
724	0265	7B		
725	0266	87		
726	0267	DC		
727	0268	C1	000088	dbt 193d,46d,248d,222d,63d,206d,197d,101d,144d
728	0269	2E		
729	026A	F8		
730	026B	DE		
731	026C	3F		
732	026D	CE		
733	026E	C5		
734	026F	65		

```
735 0270 90
736 0271 C9      000089 |      dbt 201d,233d,12d,241d,85d,180d,29d
737 0272 E9
738 0273 0C
739 0274 F1
740 0275 55
741 0276 B4
742 0277 1D
743      000090 |
744      000091 |      end
```

745 **Exercises**

746 These exercises use the programs that are included below them.

747 a) Load the copy, scan, alpha, and sumlist programs into the emulator and  
748 **verify that they work correctly**. Type at least one of these in by hand  
749 instead of using copy and paste.

750 b) Create activity diagrams for copy, scan, alpha, and sumlist. Use any  
751 drawing program that will work (<http://openoffice.org> is free and it's  
752 drawing application works well for drawing diagrams.)

753 **Copy The Contents Of list1 To list2**

```
754 %uasm65

755 ;Program Name: copy.
756 ;
757 ;Version: 1.0.
758 ;
759 ;Description: Copy the contents of list1 to list2.
760 ;
761 ;Assumptions: The numbers in the list will be no
762 ; lower than 0 and no higher than 255.

763 ;*****
764 ;Program entry point.
765     org 0200h

766 ;The X register will be used to point to each number in both list1 and list2.
767     ldx #0d

768 ;Copy the 10 bytes from list1 to list2.
769 LoopTop *
770     lda list1,x
771     sta list2,x

772     inx

773     cpx #10d

774     bne LoopTop

775 ;Exit the program.
776     brk

777 ;*****
778 ;Variables area.
```

```
779 ;This list contains 10 bytes.
780 list1 dbt 41h,42h,43h,44h,45h,46h,47h,44h,49h,4ah

781 ;This byte is placed here to make it easier to see the contents of list1
782 ;and list2 when they are dumped in the monitor.
783     dbt 0d

784 ;Set aside 10 memory locations and initialize each one to 0d.
785 list2 dbt 10d(0d)

786     end

787 %/uasm65
```

## 788 **Scan string1 And Determine How Many Capital And Lower Case A's**

## 789 **It Contains**

```
790 %uasm65

791 ;Program Name: scan.
792 ;
793 ;Version: 1.0.
794 ;
795 ;Description: Scan list1 and determine how many capital A's and lower case
796 ; a's it contains.
797 ;
798 ;Assumptions: The numbers in the list will be no
799 ; lower than 0 and no higher than 255.

800 ;*****
801 ;Program entry point.
802     org 0200h

803 ;The X register will be used to point to each ASCII character in string1
804     ldx #0d

805 LoopTop *
806     lda string1,x

807 ;If we have reached the 0 that has been placed at the end of the string, then
808 ; exit the program.
809     cmp #0d
810     beq EndOfList

811 CheckLowerCase *
812 ;If the current character is a lower case 'a', then increment LowerCaseCount.
813     cmp #'a'
814     bne CheckUpperCase
815     inc LowerCaseCount
816     jmp NextCharacter
```

```
817 CheckUpperCase  *
818 ;If the current character is an upper case 'a', then increment UpperCaseCount.
819     cmp #'A'
820     bne NextCharacter
821     inc UpperCaseCount

822 NextCharacter  *
823     inx
824     jmp LoopTop

825 EndOfList  *

826 ;Exit the program.
827     brk

828 ;*****
829 ;Variables area.

830 LowerCaseCount dbt 0d
831 UpperCaseCount dbt 0d

832 ;This list contains a string of ASCII characters.
833 string1 dbt "A bird in the hand is worth two in the bush.  Early to bed and "
834         dbt "early to rise makes a person healthy, wealthy, and wise.", dbt 0d

835     end

836 %/uasm65
```

**837 Place Capital A's In The First 10 Bytes Of alphaList, Capital B's In**  
**838 The Second 10 Bytes Of alphaList, And So On Until alphaList Is**  
**839 Filled With Letters**

```
840 %uasm65

841 ;Program Name: alpha.uasm.
842 ;
843 ;Version: 1.01.
844 ;
845 ;Description: Place capital A's in the first 10 bytes of alphaList, capital
846 B's
847 ; in the second 10 bytes of alphalist and so on until alphaList is filled
848 ; with letters.
849 ;
850 ;Assumptions: The numbers in the list will be no
851 ; lower than 0 and no higher than 255.

852 ;*****
853 ;Program entry point.
854     org 0200h
```

```
855 ;The X register will be used as a pointer.
856     ldx #0d

857     lda #10d
858     sta rowCount
859     sta columnCount

860 ;Initialize the 'A' register to be a capital 'A'.
861     lda #65d

862 LoopTop *
863 ;Place character in list at offset X.
864     sta alphalist,x

865 ;Point X to the next character position in the list.
866     inx

867 ;If we have not placed 10 characters in this row yet, then loop.
868     dec columnCount
869     bne LoopTop

870 ;Reset the column counter.
871     ldy #10d
872     sty columnCount

873 ;Increase to the next letter in the alphabet.
874     clc
875     adc #1d

876 ;If we have not filled 10 rows yet then loop.
877     dec rowCount
878     bne LoopTop

879 EndOfList *

880 ;Exit the program.
881     brk

882 ;*****
883 ;Variables area.

884 rowCount    dbt 0d
885 columnCount dbt 0d
886 alphalist   dbt 100d(?)

887     end

888 %/uasm65
```

## 889 Calculate The Sum Of The 100 Bytes That Are In numbersList

```
890 %uasm65

891 ;Program Name: sumlist.uasm.
892 ;
893 ;Version: 1.0.
894 ;
895 ;Description: Calculate the sum of the numbers that are in numberlist.
896 ;
897 ;Assumptions: The numbers in the list will be no
898 ; lower than 0 and no higher than 255.

899 ;*****
900 ;Program entry point.
901     org 0200h

902 ;The X register will be used as a pointer.
903     ldx #0d

904 ;Initialize the 16 bit wide variable "sum" to 0.  Note: 8 bits is called a
905 ; "byte" and 16 bits is called a "word".  sum+0d accesses the high byte of sum
906 ; and sum+1d accesses the low byte of sum.
907     lda #0d
908     sta sum+0d
909     sta sum+1d

910 LoopTop *
911 ;Obtain the next number from the list.
912     lda numberList,x

913 ;Add the number to the low byte of sum and then place the result back into
914 ; the low byte of sum.
915     clc
916     adc sum+1d
917     sta sum+1d

918 ;If the carry flag was set during the addition, this means that the addition
919 ; resulted in a value that was greater than 255 and the high byte of sum needs
920 ; to be incremented by 1.  If the result was 255 or less, the carry would not
921 ; be set and we can branch around the increment of the high byte of sum.
922     bcc NoCarry
923 Carry *
924     inc sum+0d

925 NoCarry *
926 ;Point to the next number in the list and loop back if we have not reached
927 ; the end of the list.
928     inx
929     cpx #100d
930     bne LoopTop

931 ;Exit the program.
932     brk

933 ;*****
```



```
934 ;Variables area.

935 ;DWD stands for Define Word and it creates a variable that is 16 bits wide.
936 ; Sum needs to be 16 bits wide because the sum of the numbers in numberList
937 ; will be greater than 255 (which is the largest number that can be held in
938 ; an 8 bit byte).
939 sum    dwd ?

940 ;This list contains 100 numbers ranging from 0 to 255.
941 numberList *
942     dbt 59d,61d,37d,128d,71d,150d,195d,130d,69d,84d
943     dbt 171d,227d,99d,214d,233d,136d,80d,253d,242d
944     dbt 112d,221d,151d,101d,117d,76d,226d,174d,205d
945     dbt 84d,78d,139d,89d,195d,243d,69d,128d,217d,215d
946     dbt 57d,100d,227d,226d,233d,238d,229d,228d,135d
947     dbt 140d,98d,211d,245d,120d,206d,198d,47d,191d
948     dbt 239d,27d,236d,12d,242d,148d,98d,11d,38d,189d
949     dbt 238d,225d,142d,214d,214d,21d,75d,17d,190d
950     dbt 178d,123d,125d,123d,10d,166d,123d,135d,220d
951     dbt 193d,46d,248d,222d,63d,206d,197d,101d,144d
952     dbt 201d,233d,12d,241d,85d,180d,29d

953     end

954 %/uasm65
```