6502 Simulator

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Recap from last presentation

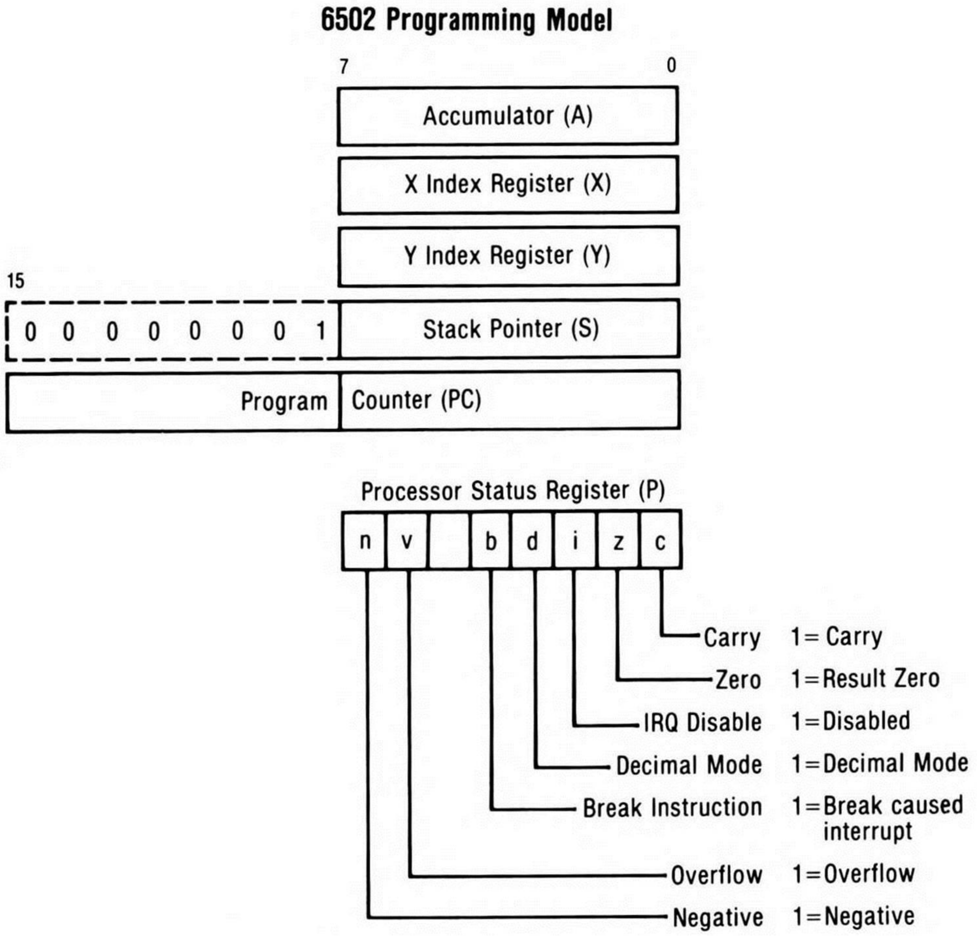
- Introduced in 1975
- Well known consoles used either the 6502 or one of its variants
    - Atari 2600
    - Nintendo Entertainment System (NES)

Used the 6507.

Used the 6502.

Hardware Recap

- Very few registers
  - One 8-bit accumulator
  - Two 8-bit index registers, X and Y
  - One 8 bit status register
  - One 8 bit stack pointer
  - One 16 bit program counter



Simulator Setup

```
struct Computer{
    byte* RAM;
    struct cpu* cpu_inst;
    struct opcode_table *opcodes;
};
```


```
20D3F8C898AAA94085782ODDF8C47820
E2F8E8A93F857820EEF8C47820F0F8E8
A9418578C47820FCF8E8A90085782006
F9C4782009F9E8A9808578C4782013F9
E8A9818578C478201DF9E8A97F8578C4
782027F9E88AA82090F985784678A578
209DF9C885784678A57820ADF9C820BD
F985780678A57820C3F9C885780678A5
7820D4F9C820E4F985786678A57820EA
F9C885786678A57820FBF9C8200AFA85
782678A5782010FAC885782678A57820
21FAA9FF85788501240138E678D00C30
0A50089006A578C900F00400000000A9
7F8578B818E678F00C100A7008B006A5
78C980F00400000000A9008578240138
C678F00C100A50089006A578C9FFF004
00000000A9808578B818C678F00C300A
7008B006A578C97FF00400000000A901
```


```
struct cpu{
    address pc;
    byte accumulator, register_x, register_y, status_register, stack_pointer;
};
```

```
struct opcode_table{
    byte opcodes_key;
    void (*opcode_function)(byte, address);
    UT_hash_handle hh;
};
```

Simulator Setup

```
OurComputer->cpu_inst->stack_pointer = 0xFF;
```

```
struct Computer{
    byte* RAM;
    struct cpu* cpu_inst;
    struct opcode_table *opcodes;
};
```

```
void stack_push(byte val){
  if(OurComputer->cpu_inst->stack_pointer == 0){
    printf("Stack full");
    exit(-1);
  }
  address stack_ptr = 1U << 8 | OurComputer->cpu_inst->stack_pointer;
  OurComputer->RAM[stack_ptr] = val;
  OurComputer->cpu_inst->stack_pointer--;
}

byte stack_pull(){
  if(OurComputer->cpu_inst->stack_pointer == 0xFF){
    printf("Stack empty");
    exit(-1);
  }
  OurComputer->cpu_inst->stack_pointer++;
  address stack_ptr = 1U << 8 | OurComputer->cpu_inst->stack_pointer;
  return OurComputer->RAM[stack_ptr];
}
```

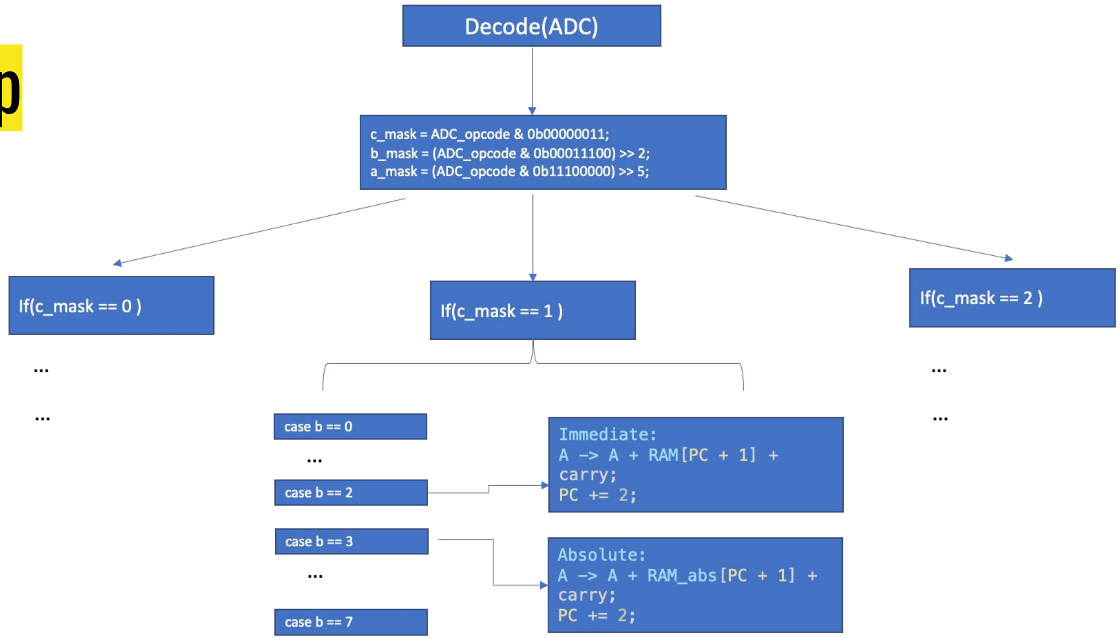
```
struct cpu{
    address pc;
    byte accumulator, register_x, register_y, status_register, stack_pointer;
};
```

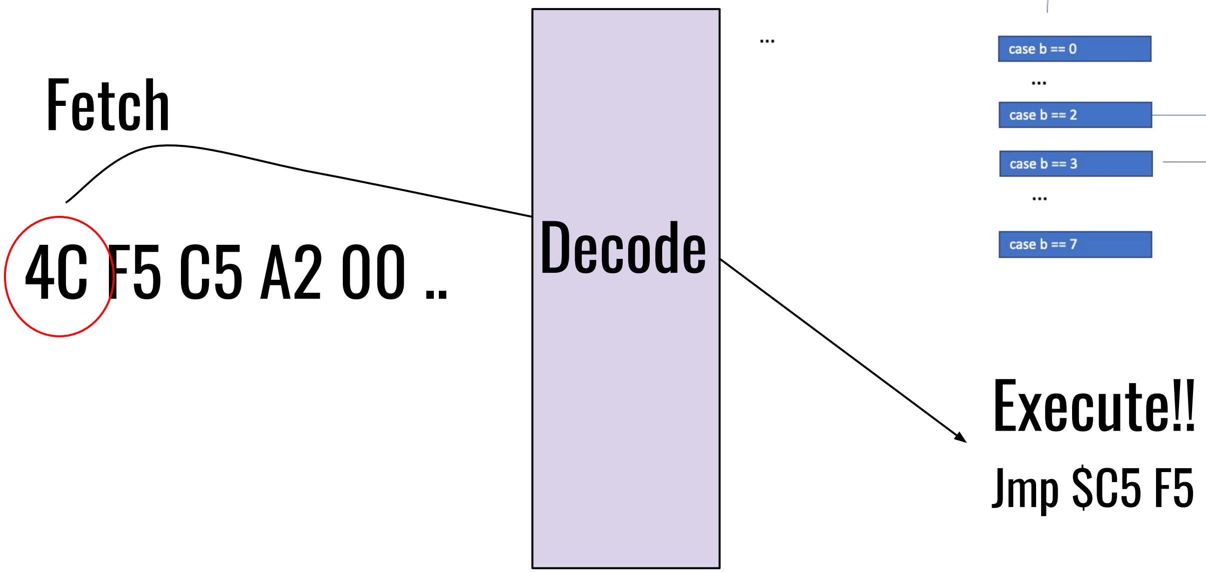
```
struct opcode_table{
    byte opcodes_key;
    void (*opcode_function)(byte, address);
    UT_hash_handle hh;
};
```

```
20D3F8C898AAA940857820DDF8C47820
E2F8E8A93F857820EEF8C47820F0F8E8
A9418578C47820FCF8E8A90085782006
F9C4782009F9E8A9808578C4782013F9
E8A9818578C478201DF9E8A97F8578C4
782027F9E88AA82090F985784678A578
209DF9C885784678A57820ADF9C820BD
F985780678A57820C3F9C885780678A5
7820D4F9C820E4F985786678A57820EA
F9C885786678A57820FBF9C8200AFA85
782678A5782010FAC885782678A57820
21FAA9FF85788501240138E678D00C30
0A50089006A578C900F00400000000A9
7F8578B818E678F00C100A7008B006A5
78C980F00400000000A9008578240138
C678F00C100A50089006A578C9FFF004
00000000A9808578B818C678F00C300A
7008B006A578C97FF00400000000A901
```

Method Architecture Recap

Fetch, Decode, Execute!





Fetch using UTHash

- Build the hashtable to store function pointers

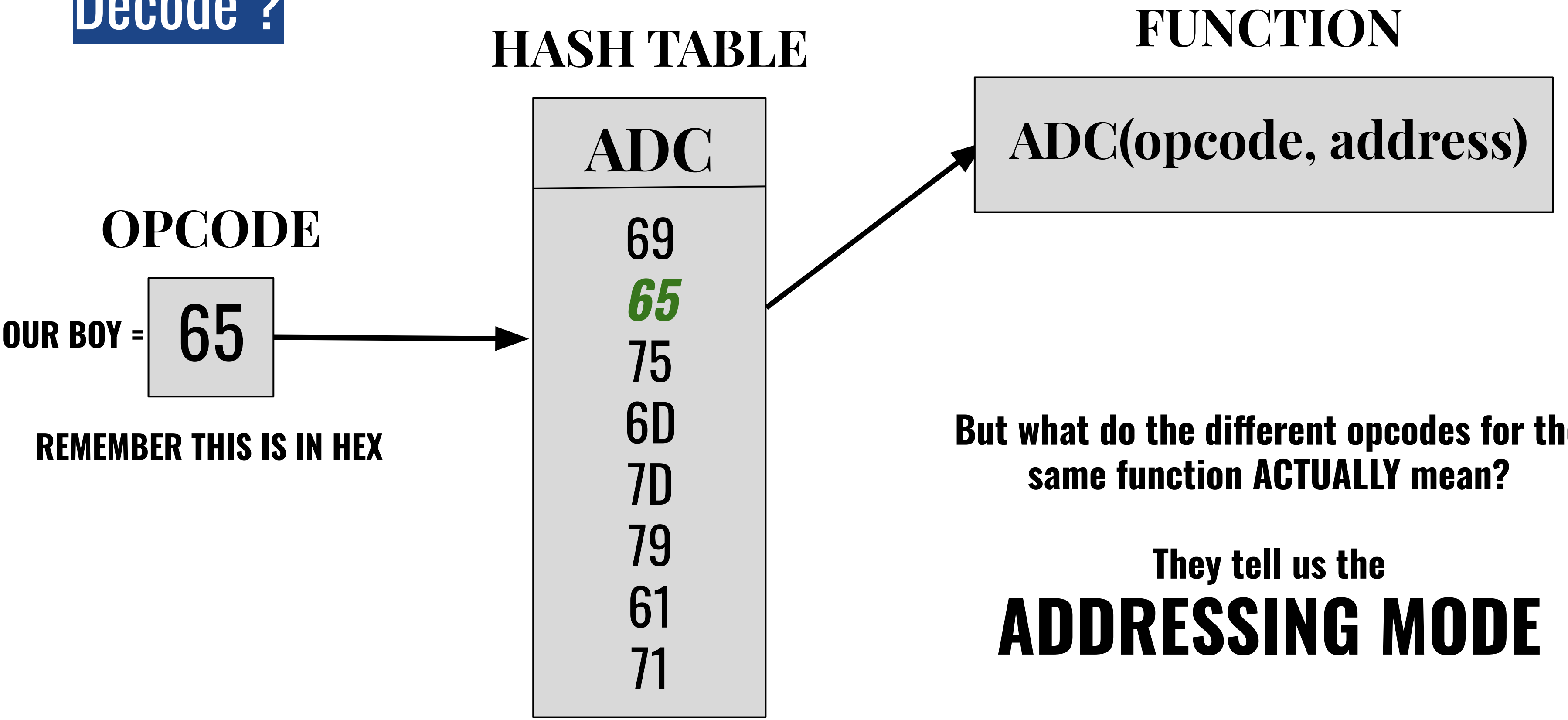
```c
void build_opcode_table(){

  int n, fd;
  byte* opcodes_keys;
  OurComputer->opcodes = NULL;

  // need to read in the opcodes
  if((opcodes_keys = (byte*) malloc((opcode_size) * sizeof(byte))) == NULL){
    exit(-1);
  }
  if((fd=open("opcode_values", O_RDONLY)) < 0){
    exit(-1);
  }
  if((n = read(fd, opcodes_keys, opcode_size)) != opcode_size){
    exit(-1);
  }
  close(fd);

  struct opcode_table* s = NULL;
  for (int i = 0; i  < opcode_size; i++){
    s = (struct opcode_table*) malloc(sizeof(*s)); // check if NULL?
    s->opcodes_key = opcodes_keys[i]; // initializing key for s
    s->opcode_function = functions[i]; // initializing the value for s
    HASH_ADD(hh,OurComputer->opcodes, opcodes_key, sizeof(uint8_t),s);
  }
}
```

UTHash Continued

- We can now invoke the correct function by reading in the opcode at the program counter

```c
void find_user(byte opcode, address pc) {

  struct opcode_table *s;
  HASH_FIND_BYTE(OurComputer->opcodes, &opcode, s);

  if(s == NULL){
    printf("err");
    return;
  }

  (*s->opcode_function) (opcode, pc);

  return;

}
```

Decode ?



But what do the different opcodes for the same function ACTUALLY mean?

They tell us the

ADDRESSING MODE

Addressing Modes, a breakdown

Group 00

- 000 -> Immediate
- 001 -> Zero page
- 010 -> Absolute
- 101 -> Zero page, x
- 111 -> Absolute, x

Group 01

- 000 -> (Zero page, x)
- 001 - Zero page
- 010 -> Immediate
- 011 -> Absolute
- 100 -> (Zero page), Y
- 101 -> Absolute, Y
- 111 -> Absolute, X

Group 10

- 000 -> Immediate
- 001 -> Zero page
- 010 -> Accumulator
- 101 -> Zero page, X
- 111 -> Absolute, X

	HEXADECIMAL		BINARY		AAA BBB CC
OUR BOY =	65	=	01100101	=	011 001 01

6502 Instructions in Detail

ADC Add Memory to Accumulator with Carry

A + M + C -> A, C

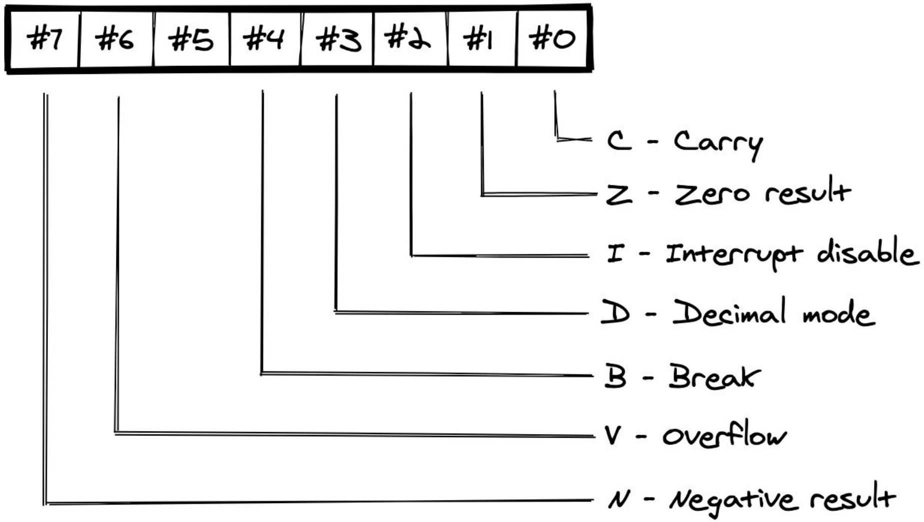
N	Z	C	I	D	V
+	+	+	-	-	+

addressing	assembler	opc	bytes	cycles
immediate	ADC #oper	69	2	2
zeropage	ADC oper	65	2	3
zeropage,X	ADC oper,X	75	2	4
absolute	ADC oper	6D	3	4
absolute,X	ADC oper,X	7D	3	4*
absolute,Y	ADC oper,Y	79	3	4*
(indirect,X)	ADC (oper,X)	61	2	6
(indirect),Y	ADC (oper),Y	71	2	5*

OUR BOY

Status Register

- Many of the opcodes set different flags in the status register
- Functions can behave differently based on these flags



Functions setting flags

- Rotate operand one bit to the right
  - 10100010 -> [c]010001
- Updates the carry flag!
- But also, updates the negative flag on input carry
- Updates zero flag on operand == 0

```
void ROR(byte opcode, address pc) {
  decode(opcode);
  byte carry = getCarryFlag(); //get the carry flag
  byte bitZero = (0b1) & OurComputer->RAM[ret.pc];  // bit 0 is shifted into carry
  OurComputer->RAM[ret.pc] = OurComputer->RAM[ret.pc] >> 1; //shift ret.arg over one bit
  OurComputer->RAM[ret.pc] = carry | ret.arg; //move carry into the 7th bit
  //Set flags
  if (carry) {
    setNegativeFlag();
  }
  else {
    clearNegativeFlag();
  }
  if (bitZero) {
    setCarryFlag();
  }
  else {
    clearCarryFlag();
    }
  if (OurComputer->RAM[ret.pc] == 0) {
    setZeroFlag();
  }
  else {
    clearZeroFlag();
  }
  OurComputer->RAM[ret.pc] += ret.arg;
}
```

Branch Commands

```
// BNE - branch on Zero Flag = 0
void BNE (byte opcode, address pc) {
    if (!getZeroFlag()) {
        OurComputer->cpu_inst->pc += OurComputer->RAM[pc + 1];
    }
    else {
        OurComputer->cpu_inst->pc += 2;
    }
    return;
}
```

Conditional jump

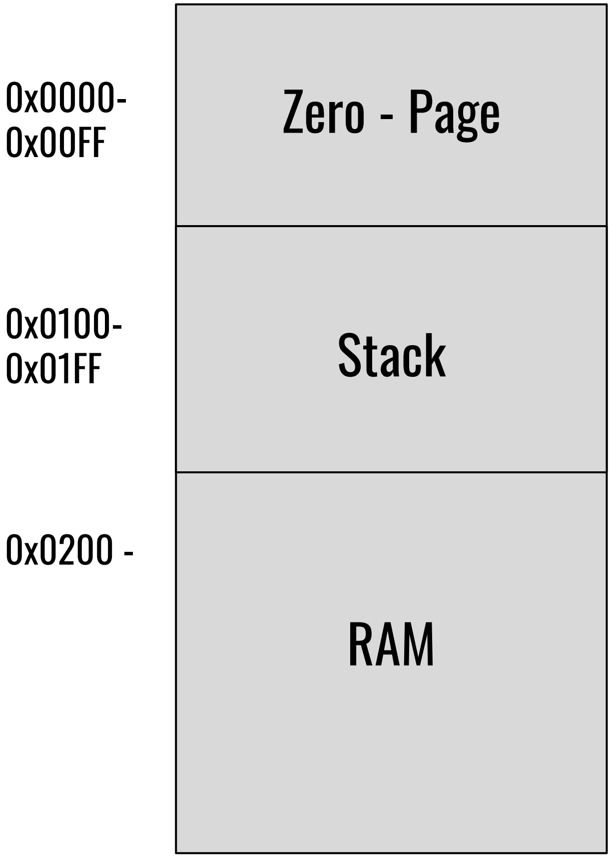
More Branch Commands

```
// BEQ - branch on Zero Flag = 1
void BEQ(byte opcode, address pc) {
  if (getZeroFlag()) {
    OurComputer->cpu_inst->pc += OurComputer->RAM[pc + 1];
  }
  OurComputer->cpu_inst->pc += 2;
  return;
}
```

Stack and Stack Pointer Register

- Created at addresses 0x100 - 0x1FF
- Memory Map:
- 0x0000 - 0x00FF: Zero page
- 0x0100 - 0x01FF: Stack

```
void stack_push(byte val){
  if(OurComputer->cpu_inst->stack_pointer == 0){
    printf("Stack full");
    exit(-1);
  }
  address stack_ptr = 1U << 8 | OurComputer->cpu_inst->stack_pointer;
  OurComputer->RAM[stack_ptr] = val;
  OurComputer->cpu_inst->stack_pointer--;
}

byte stack_pull(){
  if(OurComputer->cpu_inst->stack_pointer == 0xFF){
    printf("Stack empty");
    exit(-1);
  }
  OurComputer->cpu_inst->stack_pointer++;
  address stack_ptr = 1U << 8 | OurComputer->cpu_inst->stack_pointer;
  return OurComputer->RAM[stack_ptr];
}
```



Running Instance of Simulator

```
➜  src git:(master) ✗ ./testprogram test_opcodes.img
```

```c
int main(int argc, char* argv[]) {
  // user must pass in binary image to simulate RAM
  if (argc != 2){
    printf("%s outfile", argv[0]);
    return 1;
  }

  char* file_name = argv[1];
  // allocate memory for Computer Structure
  if((OurComputer = (struct Computer*) malloc(sizeof(struct Computer))) == NULL){
    exit(-1);
  }
  // initializing size of the RAM to 2^16
  if ((OurComputer->RAM = (byte*) malloc(RAMSIZE * sizeof(byte))) == NULL){
    exit(-1);
  }
  // initializing cpu structure inside of computer
  if((OurComputer->cpu_inst = (struct cpu*) malloc(sizeof(struct cpu))) == NULL){
    exit(-1);
  }

  read_in_binary_image(file_name); // fill struct->RAM with file_name
  build_opcode_table(); // link opcodes to functions in void_functions.c
  initialize_registers();
  start_cpu();

  free(OurComputer->RAM);
  free(OurComputer->cpu_inst);
  free(OurComputer);
  return 0;
}
```

```c
void read_in_binary_image(char* image_name){
  int n, fd;
  if((fd=open(image_name, O_RDONLY)) < 0){
    exit(-1);
  }
  if((n = read(fd, OurComputer->RAM, RAMSIZE)) != RAMSIZE){
    exit(-1);
  }
  close(fd);
}
```

Running Instance of Simulator

```
➜  src git:(master) ✗ ./testprogram test_opcodes.img
```

```c
int main(int argc, char* argv[]) {
  // user must pass in binary image to simulate RAM
  if (argc != 2){
    printf("%s outfile", argv[0]);
    return 1;
  }

  char* file_name = argv[1];
  // allocate memory for Computer Structure
  if((OurComputer = (struct Computer*) malloc(sizeof(struct Computer))) == NULL){
    exit(-1);
  }
  // initializing size of the RAM to 2^16
  if ((OurComputer->RAM = (byte*) malloc(RAMSIZE * sizeof(byte))) == NULL){
    exit(-1);
  }
  // initializing cpu structure inside of computer
  if((OurComputer->cpu_inst = (struct cpu*) malloc(sizeof(struct cpu))) == NULL){
    exit(-1);
  }

  read_in_binary_image(file_name); // fill struct->RAM with file_name
  build_opcode_table(); // link opcodes to functions in void_functions.c
  initialize_registers();
  start_cpu();

  free(OurComputer->RAM);
  free(OurComputer->cpu_inst);
  free(OurComputer);
  return 0;
}
```

```c
// Builds opcode table
void build_opcode_table(){
  int n, fd;
  byte* opcodes_keys;
  OurComputer->opcodes = NULL;
  // need to read in the opcodes
  if((opcodes_keys = (byte*) malloc((opcode_size) * sizeof(byte))) == NULL){
    exit(-1);
  }
  if((fd=open("opcode_values", O_RDONLY)) < 0){
    exit(-1);
  }
  if((n = read(fd, opcodes_keys, opcode_size)) != opcode_size){
    exit(-1);
  }
  close(fd);

  struct opcode_table* s = NULL;
  for (int i = 0; i  < opcode_size; i++){
    s = (struct opcode_table*) malloc(sizeof(*s)); // check if NULL?
    if(s == NULL){
      printf("Memory allocation err");
      exit(-1);
    }
    s->opcodes_key = opcodes_keys[i]; // initializing key for s
    s->opcode_function = functions[i]; // initializing the value for s
    HASH_ADD(hh,OurComputer->opcodes, opcodes_key, sizeof(uint8_t),s);
  }

  return;
```

Running Instance of Simulator

```
➜  src git:(master) ✗ ./testprogram test_opcodes.img
```

```c
int main(int argc, char* argv[]) {
  // user must pass in binary image to simulate RAM
  if (argc != 2){
    printf("%s outfile", argv[0]);
    return 1;
  }

  char* file_name = argv[1];
  // allocate memory for Computer Structure
  if((OurComputer = (struct Computer*) malloc(sizeof(struct Computer))) == NULL){
    exit(-1);
  }
  // initializing size of the RAM to 2^16
  if ((OurComputer->RAM = (byte*) malloc(RAMSIZE * sizeof(byte))) == NULL){
    exit(-1);
  }
  // initializing cpu structure inside of computer
  if((OurComputer->cpu_inst = (struct cpu*) malloc(sizeof(struct cpu))) == NULL){
    exit(-1);
  }

  read_in_binary_image(file_name); // fill struct->RAM with file_name
  build_opcode_table(); // link opcodes to functions in void_functions.c
  initialize_registers();
  start_cpu();

  free(OurComputer->RAM);
  free(OurComputer->cpu_inst);
  free(OurComputer);
  return 0;
}
```

```c
void start_cpu(){
  OurComputer->cpu_inst->pc = 0xC000; // starting address of the test opcodes
  OurComputer->cpu_inst->stack_pointer = 0xFD;
  for(address i = 0; i < 8991; i++){ // 8991 is the amount of test opcodes
    test_registers(i);
    execute(OurComputer->RAM[OurComputer->cpu_inst->pc], OurComputer->cpu_inst->pc);
  }
}
```

Running Instance of Simulator

```c
void start_cpu(){
    OurComputer->cpu_inst->pc = 0xC000; // starting address of the test opcodes
    OurComputer->cpu_inst->stack_pointer = 0xFD;
    for(address i = 0; i < 8991; i++){ // 8991 is the amount of test opcodes
        test_registers(i);
        execute(OurComputer->RAM[OurComputer->cpu_inst->pc], OurComputer->cpu_inst->pc);
    }
}
```

```c
void test_registers(address index){
  if(OurComputer->cpu_inst->pc != PCs[index]){
      printf("Our PC = %x \n", OurComputer->cpu_inst->pc);
      printf("Correct PC = %x \n", PCs[index]);
      printf("Wrong pc address at index %hu \n", index);
      exit(-1);
    }
  if(OurComputer->cpu_inst->accumulator != A[index]){
    printf("Our accumulator value =");
    printBits(sizeof(OurComputer->cpu_inst->accumulator), &OurComputer->cpu_inst->accumulator);
    printf("\n");
    printf("Correct accumulator value =");
    printBits(sizeof(A[index]), &A[index]);
    printf("\n");
    printf("Wrong accumulator value at index %hu \n", index);
    exit(-1);
  }
  if(OurComputer->cpu_inst->register_x != X[index]){
    printf("Our register X value = %u \n", OurComputer->cpu_inst->register_x);
    printf("Correct register X value = %u \n", X[index]);
    printf("Wrong value in register X at index %hu \n", index);
    exit(-1);
  }
  if(OurComputer->cpu_inst->register_y != Y[index]){
    printf("Our register Y value = %u \n", OurComputer->cpu_inst->register_y);
    printf("Correct register Y value = %u \n", Y[index]);
    printf("Wrong value in register Y at index %hu \n", index);
    exit(-1);
  }
  if(OurComputer->cpu_inst->stack_pointer != SP[index]){
    printf("Our stack pointer value = %u \n", OurComputer->cpu_inst->stack_pointer);
    printf("Correct stack pointer value = %u \n", SP[index]);
    printf("Wrong stack pointer value at index %hu \n", index);
    exit(-1);
  }
}
```

Running Instance of Simulator

```c
void start_cpu(){
  OurComputer->cpu_inst->pc = 0xC000; // starting address of the test opcodes
  OurComputer->cpu_inst->stack_pointer = 0xFD;
  for(address i = 0; i < 8991; i++){ // 8991 is the amount of test opcodes
    test_registers(i);
    execute(OurComputer->RAM[OurComputer->cpu_inst->pc], OurComputer->cpu_inst->pc);
  }
}
```

```c
void execute(byte opcode, address pc) {
  struct opcode_table *s; // used in execute(byte, address)
  HASH_FIND_BYTE(OurComputer->opcodes, &opcode, s);
  if(s == NULL){
    printf("Byte not in table \n");
    printf("opcode = %x \n", opcode);
    exit(-1);
  }
  (*s->opcode_function) (opcode, pc);
  return;
}
```

```c
void ADC(byte opcode, address pc) {
  decode(opcode);
  // pull high bits to test for overflow later
  byte acc_hi = ((getAccumulator() & 0x80) >> 7);
  byte arg_hi = ((ret.arg & 0x80) >> 7);
  // perform addition, cull result to 2 bytes
  int16_t res = (int16_t) (getAccumulator() + ret.arg);

  printf("res = %d \n", res);
  printf("ret.arg = %d \n", ret.arg);
  printf("Accumulator = %u \n", getAccumulator());

  OurComputer->cpu_inst->accumulator = (byte) (res & 0x00ff);
  // add 1 if carry flag set
  if(getCarryFlag()){
    OurComputer->cpu_inst->accumulator += 1;
    res += 1;
  }

  if(res > 255){
      setCarryFlag();
  }else{
      clearCarryFlag();
  }

  // pull high bits of result to test for overflow
  byte res_hi = ((getAccumulator() & 0x80) >> 7);
  if(acc_hi == arg_hi && acc_hi != res_hi){
    setOverflowFlag();
  }else{
    clearOverflowFlag();
  }
  // test high bit of result to see if negative
  if(res_hi){
    setNegativeFlag();
  }else{
    clearNegativeFlag();
  }
  // if result is 0, set zero flag
  if(getAccumulator() == 0x00){
    setZeroFlag();
  }else{
    clearZeroFlag();
  }
  update_PC();
}
```

Running Instance of Simulator

```
void ADC(byte opcode, address pc) {
  decode(opcode);
  // pull high bits to test for overflow later
  byte acc_hi = ((getAccumulator() & 0x80) >> 7);
  byte arg_hi = ((ret.arg & 0x80) >> 7);
  // perform addition, cull result to 2 bytes
  int16_t res = (int16_t) (getAccumulator() + ret.arg);

  printf("res = %d \n", res);
  printf("ret.arg = %d \n", ret.arg);
  printf("Accumulator = %u \n", getAccumulator());

  OurComputer->cpu_inst->accumulator = (byte) (res & 0x00ff);
  // add 1 if carry flag set
  if(getCarryFlag()){
    OurComputer->cpu_inst->accumulator += 1;
    res += 1;
  }

  if(res > 255){
      setCarryFlag();
  }else{
      clearCarryFlag();
  }

  // pull high bits of result to test for overflow
  byte res_hi = ((getAccumulator() & 0x80) >> 7);
  if(acc_hi == arg_hi && acc_hi != res_hi){
    setOverflowFlag();
  }else{
    clearOverflowFlag();
  }
  // test high bit of result to see if negative
  if(res_hi){
    setNegativeFlag();
  }else{
    clearNegativeFlag();
  }
  // if result is 0, set zero flag
  if(getAccumulator() == 0x00){
    setZeroFlag();
  }else{
    clearZeroFlag();
  }
  update_PC();
}
```

```
void decode(byte opcode) {
  int a_mask, b_mask, c_mask;
  a_mask = (opcode & 0b11100000) >> 5;
  b_mask = (opcode & 0b00011100) >> 2;
  c_mask = opcode & 0b00000011;
  if (c_mask == 0b00) {
    switch(b_mask) {
      // immedate
      case 0:
        ret.arg = OurComputer->RAM[getProgramCounter() + 1];
        ret.pc = getProgramCounter() + 2;
        break;
      // zeropage
      case 1:
        ret.pc = OurComputer->RAM[getProgramCounter() + 1];
        if (a_mask == 0b100) {  // STY
          ret.arg = 2;
          break;
        }
        ret.arg = OurComputer->RAM[ret.pc];
        ret.pc = getProgramCounter() + 2;
        break;
      // absolute
      case 3:
        ret.pc = read_16(getProgramCounter() + 1);
        if (a_mask == 0b010) {  // JMP
          break;
        }
        if (a_mask == 0b011) {  // JMP (abs)
          ret.pc = read_16(ret.pc);
          break;
        }
        if (a_mask == 0b100) {  // STY
          ret.arg = 3;
          break;
        }
        ret.arg = OurComputer->RAM[ret.pc];
        ret.pc = getProgramCounter() + 3;
        break;
      // zeropage, x
      case 5:
        ret.pc = OurComputer->RAM[getProgramCounter() + 1];
        ret.pc += getRegisterX();
        if (a_mask == 0b100) {  // STY
          ret.arg = 2;
```

Running Instance of Simulator

```
void ADC(byte opcode, address pc) {
  decode(opcode);
  // pull high bits to test for overflow later
  byte acc_hi = ((getAccumulator() & 0x80) >> 7);
  byte arg_hi = ((ret.arg & 0x80) >> 7);
  // perform addition, cull result to 2 bytes
  int16_t res = (int16_t) (getAccumulator() + ret.arg);

  printf("res = %d \n", res);
  printf("ret.arg = %d \n", ret.arg);
  printf("Accumulator = %u \n", getAccumulator());

  OurComputer->cpu_inst->accumulator = (byte) (res & 0x00ff);
  // add 1 if carry flag set
  if(getCarryFlag()){
    OurComputer->cpu_inst->accumulator += 1;
    res += 1;
  }

  if(res > 255){
      setCarryFlag();
  }else{
      clearCarryFlag();
  }

  // pull high bits of result to test for overflow
  byte res_hi = ((getAccumulator() & 0x80) >> 7);
  if(acc_hi == arg_hi && acc_hi != res_hi){
    setOverflowFlag();
  }else{
    clearOverflowFlag();
  }
  // test high bit of result to see if negative
  if(res_hi){
    setNegativeFlag();
  }else{
    clearNegativeFlag();
  }
  // if result is 0, set zero flag
  if(getAccumulator() == 0x00){
    setZeroFlag();
  }else{
    clearZeroFlag();
  }
  update_PC();
}
```

```
void decode(byte opcode) {
  int a_mask, b_mask, c_mask;
  a_mask = (opcode & 0b11100000) >> 5;
  b_mask = (opcode & 0b00011100) >> 2;
  c_mask = opcode & 0b00000011;
  if (c_mask == 0b00) {
    switch(b_mask) {
      // immediate
      case 0:
        ret.arg = OurComputer->RAM[getProgramCounter() + 1];
        ret.pc = getProgramCounter() + 2;
        break;
      // zeropage
      case 1:
        ret.pc = OurComputer->RAM[getProgramCounter() + 1];
        if (a_mask == 0b100) {  // STY
          ret.arg = 2;
          break;
        }
        ret.arg = OurCompu
        ret.pc = getProgra
        break;
      // absolute
      case 3:
        ret.pc = read_16(g
        if (a_mask == 0b01
          break;
        }
        if (a_mask == 0b01
          ret.pc = read_16
          break;
        }
        if (a_mask == 0b10
          ret.arg = 3;
          break;
        }
        ret.arg = OurCompu
        ret.pc = getProgra
        break;
      // zeropage, x
      case 5:
        ret.pc = OurComputer->RAM[getProgramCounter() + 1];
        ret.pc += getRegisterX();
        if (a_mask == 0b100) {  // STY
          ret.arg = 2;
```

```
struct return_{
    address pc;
    byte arg;
};

struct return_ ret;
```

Running Instance of Simulator

```c
void ADC(byte opcode, address pc) {
  decode(opcode);
  // pull high bits to test for overflow later
  byte acc_hi = ((getAccumulator() & 0x80) >> 7);
  byte arg_hi = ((ret.arg & 0x80) >> 7);
  // perform addition, cull result to 2 bytes
  int16_t res = (int16_t) (getAccumulator() + ret.arg);

  printf("res = %d \n", res);
  printf("ret.arg = %d \n", ret.arg);
  printf("Accumulator = %u \n", getAccumulator());

  OurComputer->cpu_inst->accumulator = (byte) (res & 0x00ff);
  // add 1 if carry flag set
  if(getCarryFlag()){
    OurComputer->cpu_inst->accumulator += 1;
    res += 1;
  }

  if(res > 255){
      setCarryFlag();
  }else{
      clearCarryFlag();
  }

  // pull high bits of result to test for overflow
  byte res_hi = ((getAccumulator() & 0x80) >> 7);
  if(acc_hi == arg_hi && acc_hi != res_hi){
    setOverflowFlag();
  }else{
    clearOverflowFlag();
  }
  // test high bit of result to see if negative
  if(res_hi){
    setNegativeFlag();
  }else{
    clearNegativeFlag();
  }
  // if result is 0, set zero flag
  if(getAccumulator() == 0x00){
    setZeroFlag();
  }else{
    clearZeroFlag();
  }
  update_PC();
}
```

```c
void update_PC(){
  OurComputer->cpu_inst->pc = ret.pc;
}
```

Running Instance of Simulator

```
void start_cpu(){
  OurComputer->cpu_inst->pc = 0xC000; // starting address of the test opcodes
  OurComputer->cpu_inst->stack_pointer = 0xFD;
  for(address i = 0; i < 8991; i++){ // 8991 is the amount of test opcodes
    test_registers(i);
    execute(OurComputer->RAM[OurComputer->cpu_inst->pc], OurComputer->cpu_inst->pc);
  }
}
```

```
Our accumulator value =00000100

Correct accumulator value =01011101

Wrong accumulator value at index 1100
➜  src git:(master) ✗
```

```
void test_registers(address index){
  if(OurComputer->cpu_inst->pc != PCs[index]){
    printf("Our PC = %x \n", OurComputer->cpu_inst->pc);
    printf("Correct PC = %x \n", PCs[index]);
    printf("Wrong pc address at index %hu \n", index);
    exit(-1);
  }
  if(OurComputer->cpu_inst->accumulator != A[index]){
    printf("Our accumulator value =");
    printBits(sizeof(OurComputer->cpu_inst->accumulator), &OurComputer->cpu_inst->accumulator);
    printf("\n");
    printf("Correct accumulator value =");
    printBits(sizeof(A[index]), &A[index]);
    printf("\n");
    printf("Wrong accumulator value at index %hu \n", index);
    exit(-1);
  }
  if(OurComputer->cpu_inst->register_x != X[index]){
    printf("Our register X value = %u \n", OurComputer->cpu_inst->register_x);
    printf("Correct register X value = %u \n", X[index]);
    printf("Wrong value in register X at index %hu \n", index);
    exit(-1);
  }
  if(OurComputer->cpu_inst->register_y != Y[index]){
    printf("Our register Y value = %u \n", OurComputer->cpu_inst->register_y);
    printf("Correct register Y value = %u \n", Y[index]);
    printf("Wrong value in register Y at index %hu \n", index);
    exit(-1);
  }
  if(OurComputer->cpu_inst->stack_pointer != SP[index]){
    printf("Our stack pointer value = %u \n", OurComputer->cpu_inst->stack_pointer);
    printf("Correct stack pointer value = %u \n", SP[index]);
    printf("Wrong stack pointer value at index %hu \n", index);
    exit(-1);
  }
}
```