Machine Program: Data

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based on Tiger Wang’s Jinyang Li’s slides

How hardware stores program data

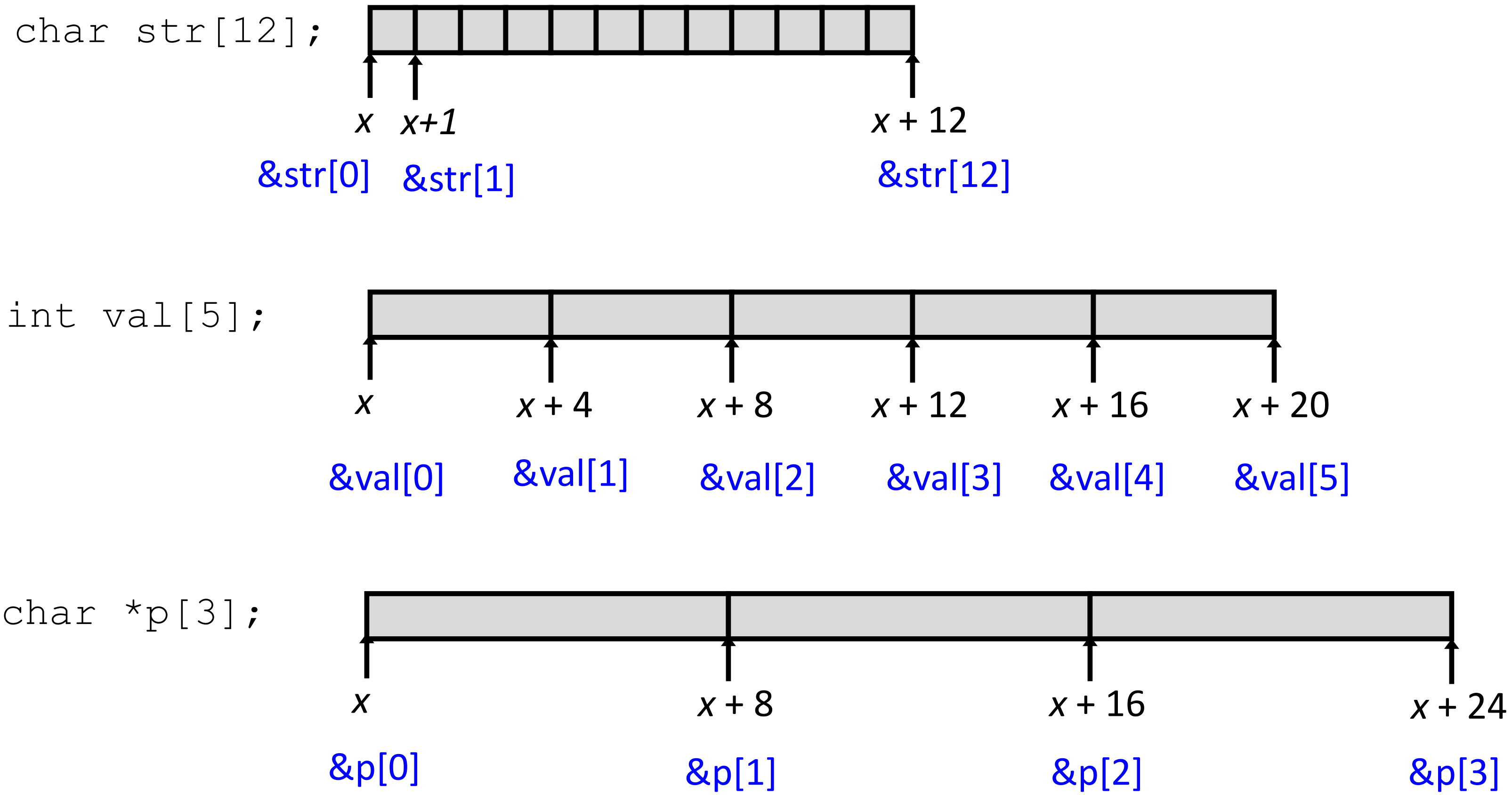
- Variables of primitive types
  - Might correspond to registers or 1,2,4,8-byte memory.

- Arrays
  - Stored in contiguous memory

- Structures
  - Stored in contiguous memory with alignment

Array Allocation

- Array is stored contiguously in memory.



```
char str[12];
```

x *x*+1 *x* + 12

&str[0] &str[1] &str[12]

```
int val[5];
```

x *x* + 4 *x* + 8 *x* + 12 *x* + 16 *x* + 20

&val[0] &val[1] &val[2] &val[3] &val[4] &val[5]

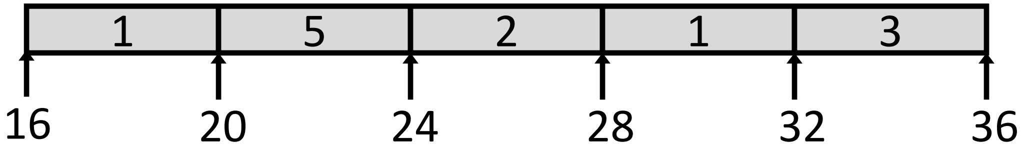
```
char *p[3];
```

x *x* + 8 *x* + 16 *x* + 24

&p[0] &p[1] &p[2] &p[3]

Array Accessing Example

```
int arr[5];
```



C code

```
int
get_digit(int *arr, long long i)
{
  return arr[i];
}
```

Suppose

%rdi contains starting address of array

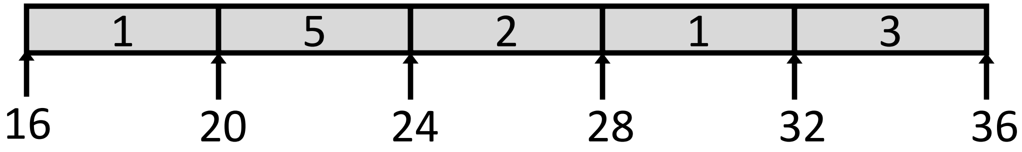
%rsi contains the index i

Assembly code

```
??? ???
```

Array Accessing Example

```
int arr[5];
```



1 5 2 1 3

16 20 24 28 32 36

```
int
get_digit(int *arr, long long i)
{
  return arr[i];
}
```

```
   # %rdi = arr
   # %rsi = i
movl (%rdi,%rsi,4), %eax  # arr[i]
```

Binary Puzzle

```
void mystery(int *arr) {
    ???
}
```

```
  movq $0, %rax
  jmp  .L3
.L4:
  addl $1, (%rdi,%rax,4)
  addq $1, %rax
.L3:
  cmpq $4, %rax
  jbe  .L4
  ret
```

rdi has the value of arr

Binary Puzzle

```
void mystery(int *arr) {
    ???
}
```

```
   movq $0, %rax
   jmp   .L3
.L4:
   addl $1, (%rdi,%rax,4)
   addq $1, %rax
.L3:
   cmpq $4, %rax
   jbe   .L4
   ret
```

```
   a = 0;
   goto .L3
```

`rdi` has the value of arr

Binary Puzzle

```
void mystery(int *arr) {
   ???
}
```

```
  movq $0, %rax
  jmp   .L3
.L4:
  addl $1, (%rdi,%rax,4)
  addq $1, %rax
.L3:
  cmpq $4, %rax
  jbe   .L4
  ret
```

```
  a = 0;
  goto .L3



.L3:
  if a <= 4
     goto .L4
  return
```

rdi has the value of arr

Binary Puzzle

```
void mystery(int *arr) {
    ???
}
```

```
   movq $0, %rax
   jmp   .L3
.L4:
   addl $1, (%rdi,%rax,4)
   addq $1, %rax
.L3:
   cmpq $4, %rax
   jbe   .L4
   ret
```

```
   a = 0;
   goto .L3
.L4
   arr[a] = arr[a] + 1
   a++
.L3:
   if a <= 4
      goto .L4
   return
```

`rdi` has the value of arr

What is the type of a?

Binary Puzzle

```
void mystery(int *arr) {
   for(unsigned long long a = 0; a <= 4; a++)
   {
     arr[a] = arr[a] + 1;
   }
}
```

```
  movq $0, %rax
  jmp  .L3
.L4:
  addl $1, (%rdi,%rax,4)
  addq $1, %rax
.L3:
  cmpq $4, %rax
  jbe  .L4
  ret
```

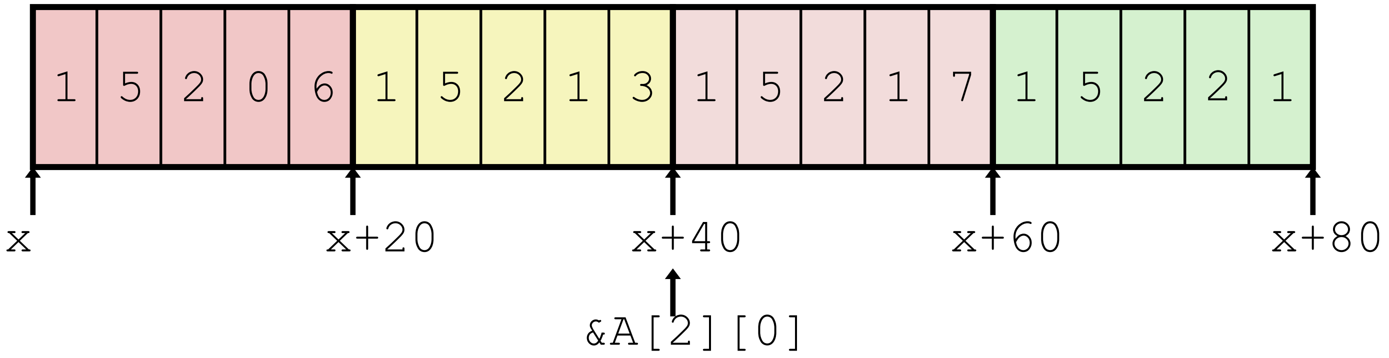
```
  a = 0;
  goto .L3
.L4
  arr[a] = arr[a] + 1
  a++
.L3:
  if a <= 4
     goto .L4
  return
```

`rdi` has the value of arr

2D arrays

```
#define ROW 4
#define COL 5
int A[ROW][COL] =
  {{1, 5, 2, 0, 6},
   {1, 5, 2, 1, 3 },
   {1, 5, 2, 1, 7 },
   {1, 5, 2, 2, 1 }};
```

- “Row-Major” ordering of all elements in memory



1	5	2	0	6	1	5	2	1	3	1	5	2	1	7	1	5	2	2	1

x+(i*COL+j)*sizeof(int)

2D Array Element Access

```
int A[4][5];

int
get_digit(long long i, long long j)
{
  return A[i][j];
}
```

i:	%rdi
j:	%rsi
return value:	%eax
&A[0][0]:	0x890d0d

```
???
```

```
x+(i*5+j)*sizeof(int)
```

2D Array Element Access

```
int A[4][5];

int
get_digit(long long i, long long j)
{
  return A[i][j];
}
```

i:	%rdi
j:	%rsi
return value:	%rax
&A[0][0]:	0x890d0d

```
 leaq   (%rdi,%rdi,4), %rax        # 5*i
 addq   %rax, %rsi                 # 5*i+j
 movl   0x890d0d(,%rsi,4), %eax# Memory[A + 4*(5*i+j)]
```

x+(i*5+j)*sizeof(int)

Identify the mystery function

```
?? mystery(char *s) {

      ???
}
```

s is kept in %rdi

```
    movl    $0x0,%eax
    jmp    L1.
L2.
    addl    $0x1,%eax
L1.
    movslq %eax,%rdx          # move sign-extended double word
    cmpb   $0x0,(%rdi,%rdx,1)
   jne    L2.
    ret
```

Identify the mystery function

```
?? mystery(char *s) {

      ???
}
```

s is kept in %rdi

```
    movl    $0x0,%eax
    jmp     L1.
L2.
    addl    $0x1,%eax
L1.
    movslq %eax,%rdx
    cmpb   $0x0,(%rdi,%rdx,1)
   jne      L2.
    ret
```

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    movl    $0x0,%eax
    jmp     L1.
L2.
    addl    $0x1,%eax
L1.
    movslq %eax,%rdx
    cmpb   $0x0,(%rdi,%rdx,1)
   jne      L2.
    ret
```

```
int a = 0;
```

Identify the mystery function

```
?? mystery(char *s) {

      ???
}
```

```
       movl    $0x0,%eax
       jmp     L1.
  L2.
       addl    $0x1,%eax
  L1.
       movslq %eax,%rdx
       cmpb   $0x0,(%rdi,%rdx,1)
       jne     L2.
       ret
```

```
int a = 0;
goto L1;
```

Identify the mystery function

```
?? mystery(char *s) {

      ???
}
```

```
s is kept in %rdi
```

```
      movl    $0x0,%eax
      jmp     L1.
  L2.
      addl    $0x1,%eax
  L1.
      movslq %eax,%rdx
      cmpb   $0x0,(%rdi,%rdx,1)
     jne      L2.
      ret
```

```
    int a = 0;
    goto L1;


L1.
    long d = a;
```

Identify the mystery function

```
?? mystery(char *s) {

      ???
}
```

```
      movl    $0x0,%eax
      jmp     L1.
  L2.
      addl    $0x1,%eax
  L1.
      movslq %eax,%rdx
      cmpb   $0x0,(%rdi,%rdx,1)
     jne      L2.
      ret
```

```
     int a = 0;
     goto L1;


L1.
     long d = a;
     if(0 != s[d])
```

Identify the mystery function

```
?? mystery(char *s) {

      ???
}
```

s is kept in %rdi

```
      movl    $0x0,%eax
      jmp     L1.
  L2.
      addl    $0x1,%eax
  L1.
      movslq %eax,%rdx
      cmpb   $0x0,(%rdi,%rdx,1)
     jne      L2.
      ret
```

```
    int a = 0;
    goto L1;


L1.
    long d = a;
    if(0 != s[d]) {
       goto L2;
    }
```

Identify the mystery function

```
?? mystery(char *s) {

      ???
}
```

```
      movl    $0x0,%eax
      jmp     L1.
  L2.
      addl    $0x1,%eax
  L1.
      movslq %eax,%rdx
      cmpb   $0x0,(%rdi,%rdx,1)
     jne      L2.
      ret
```

```
    int a = 0;
    goto L1;
L2.
    a = a  + 1;
L1.
    long d = a;
    if(0 != s[d]) {
       goto L2;
    }
```

Identify the mystery function

```
int mystery(char *s) {

    int a = 0;
    long d = a;
    while(0 != s[d]) {
       a = a + 1;
       d = a;
    }
    return a;
}
```

```
    int a = 0;
    goto L1;
L2.
    a = a  + 1;
L1.
    long d = a;
    if(0 != s[d]) {
       goto L2;
    }
    ret;
```

```
        movl    $0x0,%eax
        jmp     L1.
    L2.
        addl    $0x1,%eax
    L1.
        movslq %eax,%rdx
        cmpb   $0x0,(%rdi,%rdx,1)
       jne      L2.
       ret
```

```
s is kept in %rdi
```

Structure

```
struct node {
    int a[4];
    long i;
    struct node *next;
};
```

Structure

```
struct node {
    int a[4];
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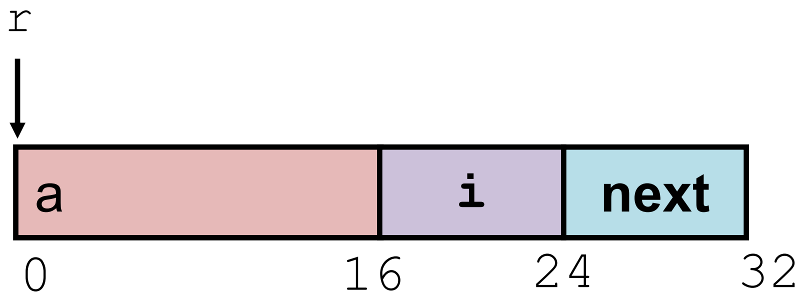
};
```



Structure

```
struct node {
    int a[4];
    long i;
    struct node *next;
};
```

Register	Value
`%rdi`	`r`
`%rsi`	`val`

```
void func
  (struct node *r, int val)
{
    while(r) {
        int i = r->i;
        r->a[i] = val;
        r = r->next;
    }
}
```

Structure

```
struct node {
    int a[4];
    long i;
    struct node *next;
};
```

Register	Value
%rdi	**r**
%esi	**val**

```
void
foo(struct node *r, int val)
{
    while(r) {
        int i = r->i;
        r->a[i] = val;
        r = r->next;
    }
}
```

```
.L11:                              # loop:
  movslq  16(%rdi), %rax           #   i = M[r+16]
  movl    %esi, (%rdi,%rax,4)      #   M[r+4*i] = val
  movq    24(%rdi), %rdi           #   r = M[r+24]
  testq   %rdi, %rdi               #   test r
  jne     .L11                     #   if !=0 goto loop
```