Topic 6: C Dynamic Allocation

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1 Using malloc to Allocate Memory 2
2 Using free to Deallocate Memory 8
3 Mapping Conceptual Storage to Machine Memory 10

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1. Using `malloc` to Allocate Memory

- Let’s revisit an example we saw in a previous topic
- Assume we wish to refactor appending a node to a chain into its own function

Draw a state diagram corresponding to the execution of this program

```c
typedef struct _node_t
{
    int value;
    struct _node_t* next_ptr;
} node_t;
	node_t* append( node_t* n_ptr, int value )
{
    node_t node;
    node.value = value;
    node.next_ptr = n_ptr;
    return &node;
}

int main( void )
{
    node_t* n_ptr = NULL;
    n_ptr = append( n_ptr, 3 );
    n_ptr = append( n_ptr, 4 );
    return 0;
}
```
Let’s consider a similar idea for arrays
Assume we wish to refactor allocating an array and then initializing all elements to zero into its own function

```c
#include <stddef.h>

int* init_array( int n )
{
    int x[n];

    for ( int i=0; i<n; i++ )
        x[i] = 0;

    return x;
}

int main( void )
{
    int* a = init_array(3);
    return 0;
}
```

List two errors with this function:

1. ________________________________

2. ________________________________
1. Using `malloc` to Allocate Memory

- **Dynamic memory allocation** uses the heap (new region of memory)
- Because dynamically allocated variables are not on a function’s stack frame, they are not deallocated when a function returns
- We can dynamically allocate variables on the heap using `malloc`
- `malloc` takes the number of bytes to allocate as a parameter and returns a pointer to the new variable allocated on the heap
- Since the amount of memory allocated is dynamic, we can create arrays where the number of elements is not known until runtime

- `malloc` is defined in `stdlib.h`

```c
int* a_ptr = malloc( sizeof(int) );
*a_ptr = 42;

int* b_ptr = malloc( 4 * sizeof(int) );
b_ptr[0] = 10;
b_ptr[1] = 11;
b_ptr[2] = 12;
b_ptr[3] = 13;
```
1. Using malloc to Allocate Memory

Draw a state diagram corresponding to the execution of this program

```c
typedef struct {
    double real;
    double imag;
} complex_t;

int main( void ) {
    complex_t* c_ptr0 = malloc( sizeof(complex_t) );
    c_ptr0->real = 1.5;
    c_ptr0->imag = 3.5;

    complex_t* c_ptr1 = malloc( sizeof(complex_t) );
    c_ptr1->real = c_ptr0->real;
    c_ptr1->imag = c_ptr0->imag;

    return 0;
}
```
• Assume we wish to refactor appending a node to a chain into its own function

```c
typedef struct _node_t
{
    int value;
    struct _node_t* next_ptr;
} node_t;

node_t* append( node_t* n_ptr, int value )
{
    node_t* new_ptr = malloc( sizeof(node_t) );
    new_ptr->value = value;
    new_ptr->next_ptr = n_ptr;
    return new_ptr;
}

int main( void )
{
    node_t* n_ptr = NULL;
    n_ptr = append( n_ptr, 3 );
    n_ptr = append( n_ptr, 4 );
    return 0;
}
```
• Assume we wish to refactor allocating an array and then initializing all elements to zero into its own function

```c
#include <stddef.h>

int* init_array( int n )
{
    int* x = malloc( n * sizeof(int) );

    for ( int i=0; i<n; i++ )
        x[i] = 0;

    return x;
}

int main( void )
{
    int* a = init_array(3);
    return 0;
}
```

How does this address the two errors we identified earlier?

1. 

2. 

2. Using `free` to Deallocate Memory

Draw a state diagram corresponding to the execution of this program

```c
typedef struct {
    double real;
    double imag;
} complex_t;

int main( void )
{
    complex_t* c_ptr = malloc( sizeof(complex_t) );
    c_ptr->real = 1.5;
    c_ptr->imag = 3.5;

    c_ptr = malloc( sizeof(complex_t) );
    c_ptr->real = 2.5;
    c_ptr->imag = 4.5;
    return 0;
}
```
2. Using `free` to Deallocate Memory

- Every call to `malloc` must have corresponding call to `free`
- `free` takes a pointer to a dynamically allocated variable

```c
typedef struct
{
    double real;
    double imag;
} complex_t;

int main( void )
{
    complex_t* c_ptr = malloc( sizeof(complex_t) );
    c_ptr->real = 1.5;
    c_ptr->imag = 3.5;
    free( c_ptr );

    c_ptr = malloc( sizeof(complex_t) );
    c_ptr->real = 2.5;
    c_ptr->imag = 4.5;
    free( c_ptr );

    return 0;
}
```
3. Mapping Conceptual Storage to Machine Memory

- Recall that our current use of state diagrams is conceptual.
- Real machine uses memory to store variables.
- Real machine does not use “arrows”, uses memory addresses.
- Heap is stored above code and grows up.
### 3. Mapping Conceptual Storage to Machine Memory

```c
int a = 3;
int* a_ptr = &a;

int* b_ptr = malloc( sizeof(int) );
*b_ptr = 42;

int* c = malloc( 4 * sizeof(int) );
c[0] = 10;
c[1] = 11;
c[2] = 12;
c[3] = 13;
```

#### Memory

(4B word addr)

<table>
<thead>
<tr>
<th>Address</th>
<th>Value</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>124</td>
<td></td>
</tr>
</tbody>
</table>

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**Topic 6: C Dynamic Allocation**
Machine memory in real systems

- Machine memory size ranges from KBs (embedded) to TBs (server)
- Lowest address range reserved to detect NULL pointer dereference
- Static data region is used for global variables
- Machine memory as shown is really the virtual memory space
- Different programs have their own virtual memory spaces mapped to a single large physical memory space