

ECE 220

Lecture x0019 - 11/05

Linked data structures & C to LC3

Recap & reminders

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- Reminders

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 - Quizzes next week (penultimate one!)

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 - MT2 scores to be released by tonight

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 - Quizzes next week (penultimate one!)
 - MT2 scores to be released by tonight
 - Regrade deadline is Sunday
- Happy Election Day!

Structs in LC3

Memory allocation

Memory allocation

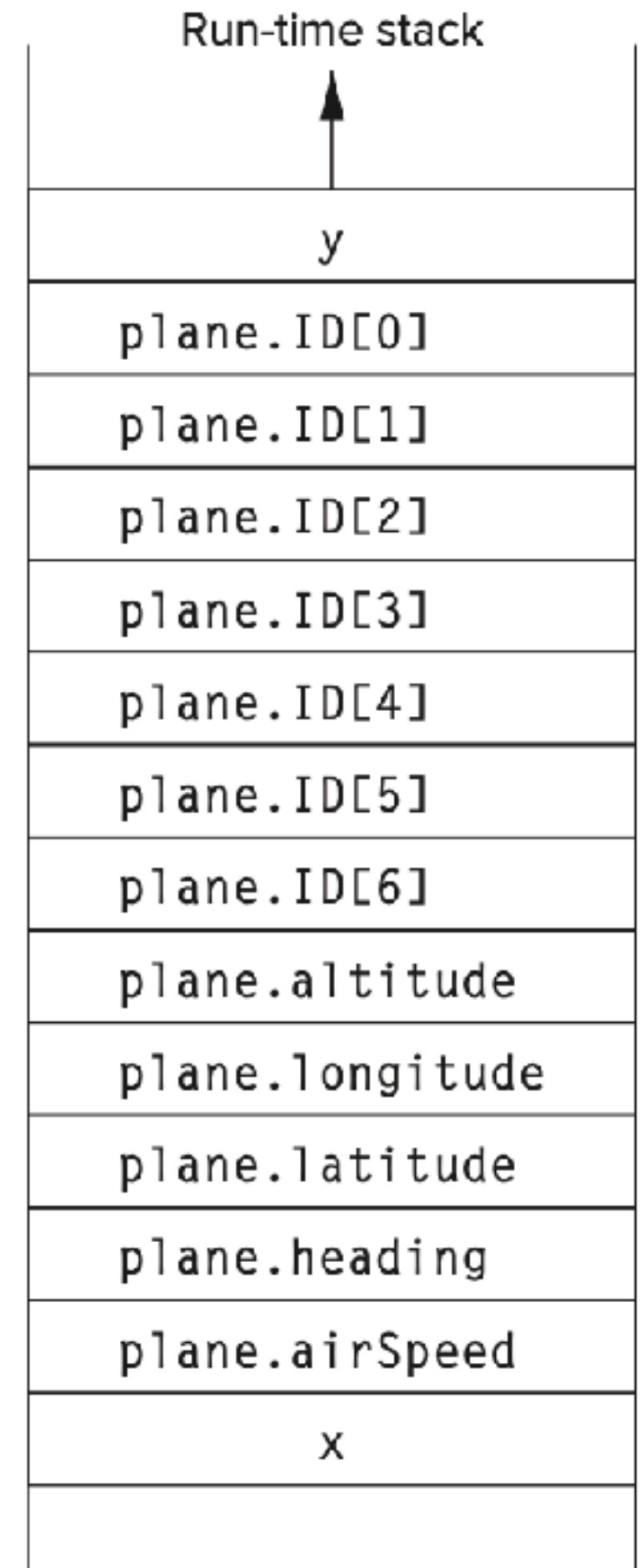
```
struct flightType {  
    char ID[7];           // Max 6 characters  
    int altitude;        // in meters  
    int longitude;       // in tenths of degrees  
    int latitude;        // in tenths of degrees  
    int heading;         // in tenths of degrees  
    double airSpeed;     // in kilometers/hour  
};
```

Memory allocation

```
struct flightType {  
    char ID[7];           // Max 6 characters  
    int altitude;        // in meters  
    int longitude;       // in tenths of degrees  
    int latitude;        // in tenths of degrees  
    int heading;         // in tenths of degrees  
    double airSpeed;     // in kilometers/hour  
};  
  
int x;  
struct flightType plane;  
int y;
```

Memory allocation

```
struct flightType {  
    char ID[7];           // Max 6 characters  
    int altitude;        // in meters  
    int longitude;       // in tenths of degrees  
    int latitude;        // in tenths of degrees  
    int heading;         // in tenths of degrees  
    double airSpeed;     // in kilometers/hour  
};  
  
int x;  
struct flightType plane;  
int y;
```



Memory representation

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;

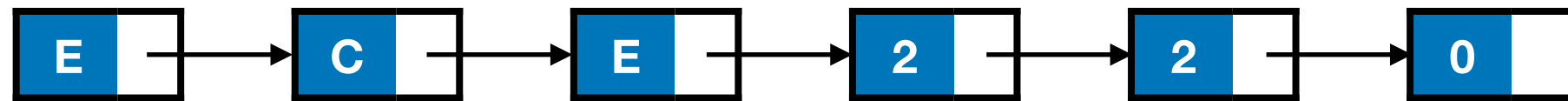
int main(){
    node N3, N2, N1;
    N1.symbol = 'E'
    N2.symbol = 'C'
    N3.symbol = 'E'

    N1.next = &N2;
    N2.next = &N3;
    N3.next = NULL;
}
```

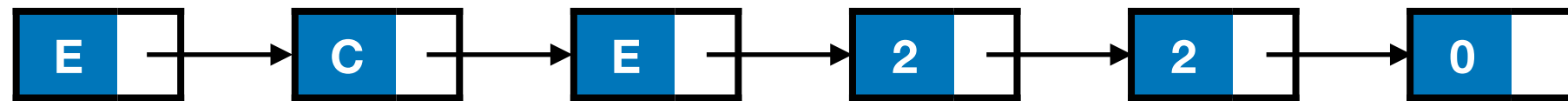
	Address	Value	Symbol
N1	x6000	E	N1.symbol
	x6001	x6002	N1.next
N2	x6002	C	N2.symbol
	x6003	x6004	N2.next
N3	x6004	E	N3.symbol
	x6005	NULL	N3.next

Printing a linked list

Printing a linked list



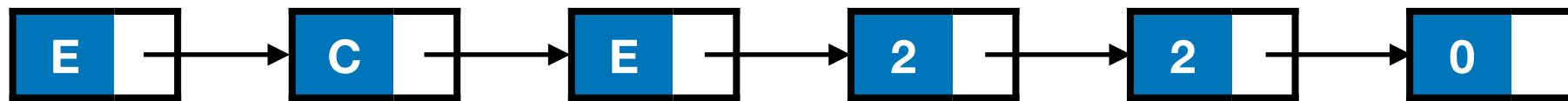
Printing a linked list



```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```


Printing a linked list



```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;

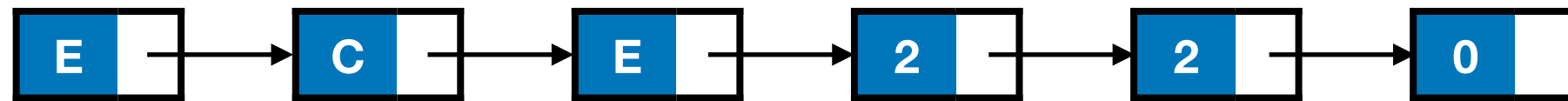
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

```
.ORIG x3000

MAIN
    LD R5, RSTACK
    LD R6, RSTACK
    LD R0, HEAD
    STR R0, R6, #0 ; push argument onto stack
    ADD R6, R6, #-1
    JSR PRINT_LIST
    ADD R6, R6, #2 ; caller teardown (pop retval & args)
    HALT

HEAD .FILL x4004
RSTACK .FILL x7000
```

Printing a linked list



What is at memory location x4004?

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

```
.ORIG x3000

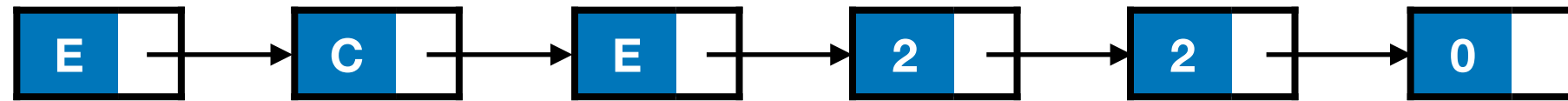
MAIN
    LD R5, RSTACK
    LD R6, RSTACK
    LD R0, HEAD
    STR R0, R6, #0 ; push argument onto stack
    ADD R6, R6, #-1
    JSR PRINT_LIST
    ADD R6, R6, #2 ; caller teardown (pop retval & args)
    HALT
```

```
HEAD .FILL x4004
RSTACK .FILL x7000
```

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



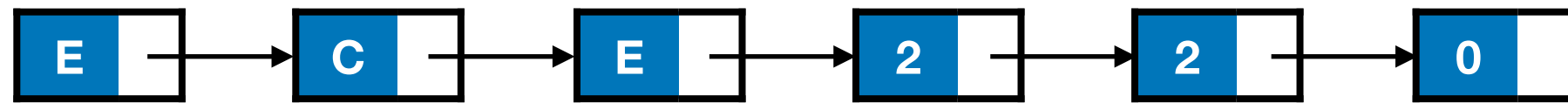
```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

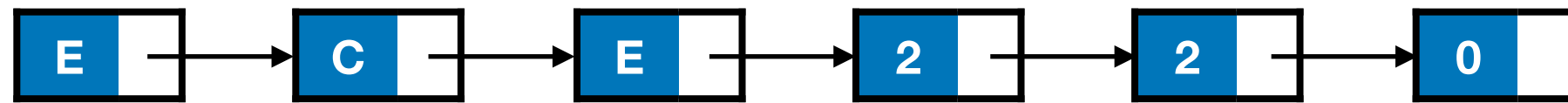


x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



Head pointer →	x4004	69	x0045
	x4005	16390	x4006
	x4006	67	x0043
	x4007	16392	x4008
	x4008	69	x0045
	x4009	16394	x400A
	x400A	50	x0032
	x400B	16396	x400C
	x400C	50	x0032
	x400D	16398	x400E
	x400E	48	x0030

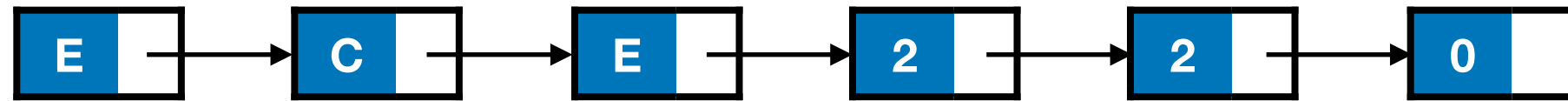

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list



Head pointer →

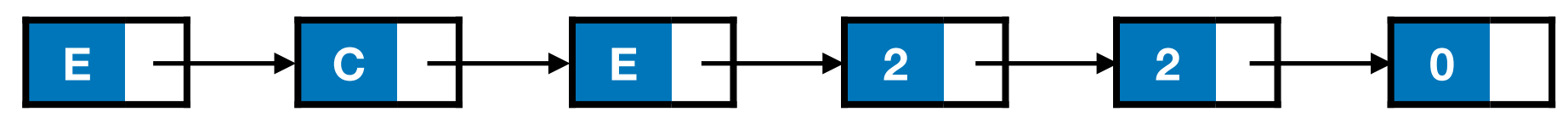
x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

What is at memory location x7000?

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000

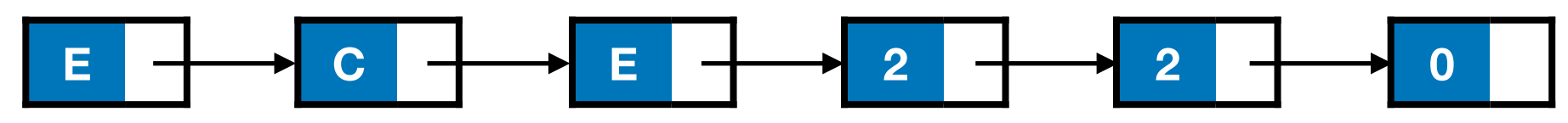
Head pointer	→	x4004	69	x0045
		x4005	16390	x4006
		x4006	67	x0043
		x4007	16392	x4008
		x4008	69	x0045
		x4009	16394	x400A
		x400A	50	x0032
		x400B	16396	x400C
		x400C	50	x0032
		x400D	16398	x400E
		x400E	48	x0030
	

What is at memory location x7000?

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
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        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000

Head pointer	→	x4004	69	x0045
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		x4007	16392	x4008
		x4008	69	x0045
		x4009	16394	x400A
		x400A	50	x0032
		x400B	16396	x400C
		x400C	50	x0032
		x400D	16398	x400E
		x400E	48	x0030
	

What is at memory location x7000?

```
.ORIG x3000

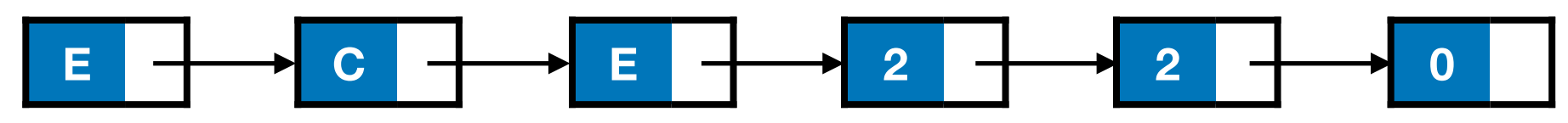
MAIN
```



```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000

Head pointer	→	x4004	69	x0045
		x4005	16390	x4006
		x4006	67	x0043
		x4007	16392	x4008
		x4008	69	x0045
		x4009	16394	x400A
		x400A	50	x0032
		x400B	16396	x400C
		x400C	50	x0032
		x400D	16398	x400E
		x400E	48	x0030
	

What is at memory location x7000?

```
.ORIG x3000

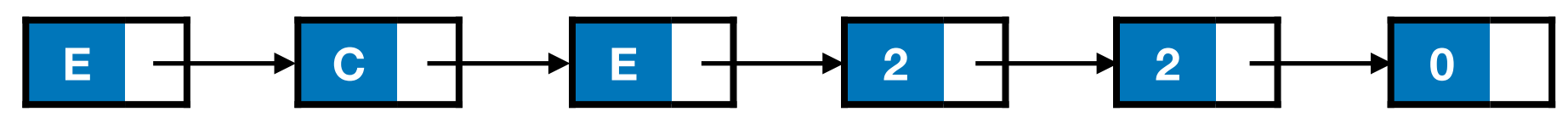
MAIN
    LD R5, RSTACK
```

R5 →

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
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    else{
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        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



Runtime stack

...
x6FF5
x6FF6
x6FF7
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x6FF9
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x6FFB
x6FFC
x6FFD
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Head pointer	→	x4004	69	x0045
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		x4008	69	x0045
		x4009	16394	x400A
		x400A	50	x0032
		x400B	16396	x400C
		x400C	50	x0032
		x400D	16398	x400E
		x400E	48	x0030
	

What is at memory location x7000?

```
.ORIG x3000

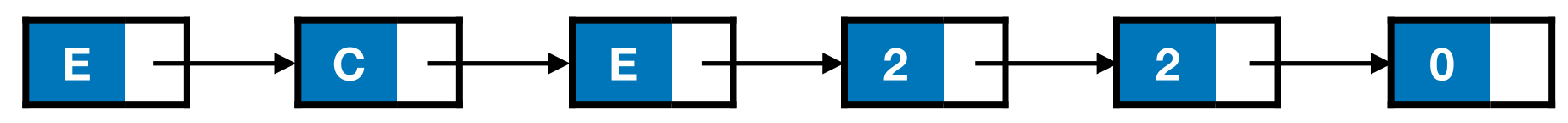
MAIN
    LD R5, RSTACK
    LD R6, RSTACK
```

R5 → R6 →

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000

Head pointer	→	x4004	69	x0045
		x4005	16390	x4006
		x4006	67	x0043
		x4007	16392	x4008
		x4008	69	x0045
		x4009	16394	x400A
		x400A	50	x0032
		x400B	16396	x400C
		x400C	50	x0032
		x400D	16398	x400E
		x400E	48	x0030
	

What is at memory location x7000?

```
.ORIG x3000

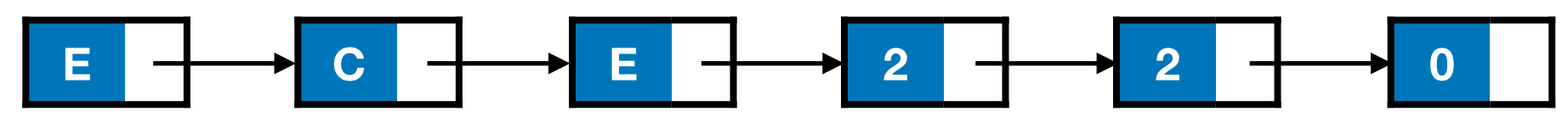
MAIN
    LD R5, RSTACK
    LD R6, RSTACK
    LD R0, HEAD
```

R5 → R6 →

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000
x4004

Head pointer	→	x4004	69	x0045
		x4005	16390	x4006
		x4006	67	x0043
		x4007	16392	x4008
		x4008	69	x0045
		x4009	16394	x400A
		x400A	50	x0032
		x400B	16396	x400C
		x400C	50	x0032
		x400D	16398	x400E
		x400E	48	x0030
	

What is at memory location x7000?

```
.ORIG x3000
```

MAIN

```
LD R5, RSTACK
LD R6, RSTACK
LD R0, HEAD
```

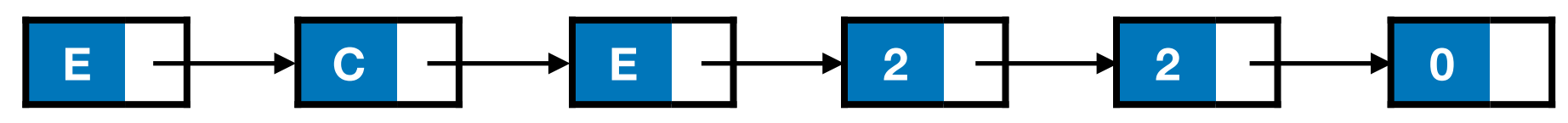
R5 → R6 →

```
STR R0, R6, #0 ; push argument onto stack
```

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



Runtime stack

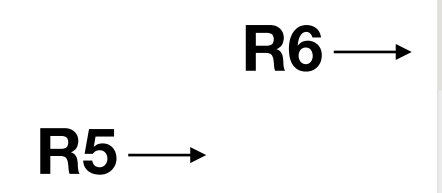
...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000
x4004

Head pointer	→	x4004	69	x0045
		x4005	16390	x4006
		x4006	67	x0043
		x4007	16392	x4008
		x4008	69	x0045
		x4009	16394	x400A
		x400A	50	x0032
		x400B	16396	x400C
		x400C	50	x0032
		x400D	16398	x400E
		x400E	48	x0030
	

What is at memory location x7000?

```
.ORIG x3000
```

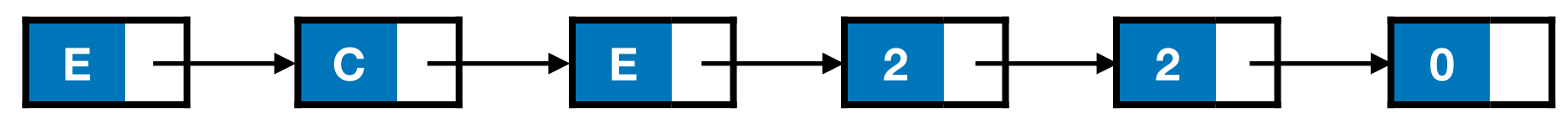
```
MAIN
    LD R5, RSTACK
    LD R6, RSTACK
    LD R0, HEAD
    STR R0, R6, #0 ; push argument onto stack
    ADD R6, R6, #-1
```



```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list



Runtime stack



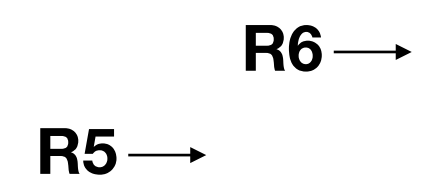
Head pointer	→	x4004	69	x0045
		x4005	16390	x4006
		x4006	67	x0043
		x4007	16392	x4008
		x4008	69	x0045
		x4009	16394	x400A
		x400A	50	x0032
		x400B	16396	x400C
		x400C	50	x0032
		x400D	16398	x400E
		x400E	48	x0030
	

What is at memory location x7000?

```
.ORIG x3000

MAIN
    LD R5, RSTACK
    LD R6, RSTACK
    LD R0, HEAD
    STR R0, R6, #0 ; push argument onto stack
    ADD R6, R6, #-1
    JSR PRINT_LIST
    ADD R6, R6, #2 ; caller teardown (pop retval & args)
    HALT

HEAD .FILL x4004
RSTACK .FILL x7000
```



```

typedef struct Node{
    char symbol;
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void print_list(node *cursor){
    if (cursor==NULL)
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    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

P
;;Part 1 - callee build up

x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

← **Head**

R5 →

R6 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	
x6FFE	
x6FFF	
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
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    }
}

```

Printing a linked list

```

P
;;
ADD R6, R6, #-1 ;make space for return value

```

x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

← **Head**

R6 →

R5 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	
x6FFE	
x6FFF	
x7000	x4004


```

typedef struct Node{
    char symbol;
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    if (cursor==NULL)
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        printf("%c", cursor->symbol);
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    }
}

```

Printing a linked list

```

P
;;
ADD R6, R6, #-1 ;make space for return value

```

x4004	69	x0045
x4005	16390	x4006
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x4007	16392	x4008
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x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

← **Head**

R6 →

R5 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	
x6FFE	
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

```

P
;;

ADD R6, R6, #-1

```

x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

← Head

R6 →

R5 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

```

P
;;

STR R5, R6, #0 ;push caller frame pointer

```

x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

← **Head**

R6 →

R5 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

P
;;

```
ADD R5, R6, #-1 ;set new frame pointer
```

x4004	69	x0045	← Head
x4005	16390	x4006	R5 →
x4006	67	x0043	R6 →
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

Printing a linked list

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

x4004	69	x0045	← Head
x4005	16390	x4006	R5 →
x4006	67	x0043	R6 →
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

```
P
;;

;
;;
;
;if(cursor == NULL) skip to the end;
```

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
	x4004

```

P
;;

;
;;
;
;
LDR R1, R5, #4 ;load head to R1

```

x4004	69	x0045	← Head
x4005	16390	x4006	R5 →
x4006	67	x0043	
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

R6 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
	x4004

```

P
;;

;
;;
;
;

;

```

x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

← **Head**

R5 →

R6 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
69	x4004

```

PRINT_LIST
;;Part 1 - callee build up
    ADD R6, R6, #-1      ;make space for return value

    ADD R6, R6, #-1

;
;;Part 2 - implement function logic
;
;if(cursor == NULL) skip to the end;

    BRz TEAR_DOWN      ;if head null, nothing to do
;
;else printf("%c", cursor->symbol);

    OUT

```

x4004	69	x0045	← Head
x4005	16390	x4006	R5 →
x4006	67	x0043	R6 →
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004


```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
69	x4004

x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

← **Head**

R5 →

R6 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

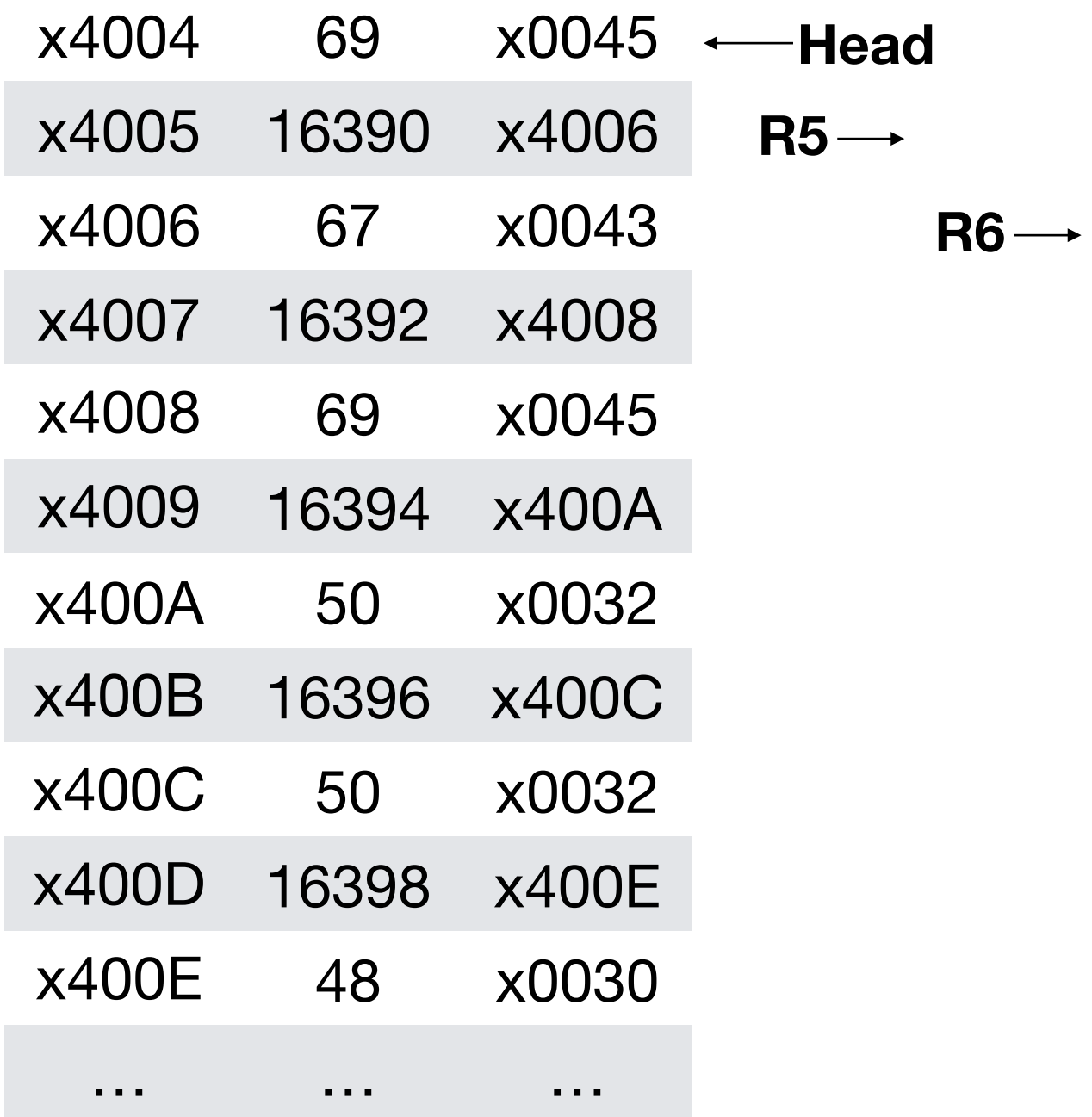
```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list

R0	R1
69	x4004

```
;
LDR R1, R1, #1 ;load head->next to R1
```



Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
69	x4006

```

;
LDR R1, R1, #1 ;load head->next to R1

```

x4004	69	x0045	← Head
x4005	16390	x4006	R5 →
x4006	67	x0043	R6 →
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
69	x4006

```
ADD R6, R6, #-1
```

x4004	69	x0045	← Head
x4005	16390	x4006	R5 → R6 →
x4006	67	x0043	
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	
x6FFC	
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

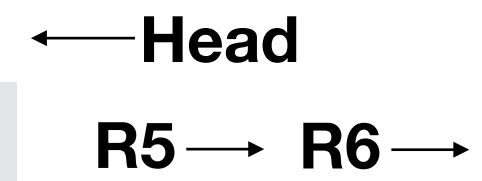
R0	R1
69	x4006

```

;
;
STR R1, R6, #0 ;push head->next to the stack

```

x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...



Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000

x4006 CFP Ret Addr Ret Val x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
69	x4006

```
ADD R6, R6, #-1
```

x4004	69	x0045	← Head
x4005	16390	x4006	R5 → R6 →
x4006	67	x0043	
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

Runtime stack

...	...
x6FF5	...
x6FF6	Ret Addr
x6FF7	Ret Val
x6FF8	x4008
x6FF9	CFP
x6FFA	Ret Addr
x6FFB	Ret Val
x6FFC	x4006
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
69	x4006

ADD R6, R6, #-1

x4004	69	x0045	← HeadR6 →
x4005	16390	x4006	R5 →
x4006	67	x0043	
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	Ret Val
x6FFC	x4006
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
69	x4006

JSR PRINT_LIST

x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

← Head

R5 →

R6 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	Ret Val
x6FFC	x4006
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004


```
typedef struct Node{
    char symbol;
    struct Node *next;
}node;
```

```
void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}
```

Printing a linked list

R0	R1
69	x4006

```
;
;
ADD R6, R6, #2 ; caller stack tear down
```

x4004	69	x0045	← Head
x4005	16390	x4006	R5 →
x4006	67	x0043	R6 →
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000

Ret Val: x4006, x4004
CFP: x4006

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
69	x4006

x4004	69	x0045
x4005	16390	x4006
x4006	67	x0043
x4007	16392	x4008
x4008	69	x0045
x4009	16394	x400A
x400A	50	x0032
x400B	16396	x400C
x400C	50	x0032
x400D	16398	x400E
x400E	48	x0030
...

← **Head**

R5 →

R6 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	Ret Val
x6FFC	x4006
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1
69	x4006

```

;
;
;skip here if head is null

```

x4004	69	x0045	← Head
x4005	16390	x4006	R5 →
x4006	67	x0043	R6 →
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000

Ret Val: x4006, x4004
CFP: x4006

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1	R5	R7
69	x4006		

```

;
;
;
;;Part 3 - callee tear down (preparing to return)

```

x4004	69	x0045	← Head
x4005	16390	x4006	R5 →
x4006	67	x0043	R6 →
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	Ret Val
x6FFC	x4006
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1	R5	R7
69	x4006		Ret Addr

Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000

;

;

x4004	69	x0045	← Head
x4005	16390	x4006	R5 →
x4006	67	x0043	R6 →
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

;

;;

TEAR_DOWN

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1	R5	R7
69	x4006	CFP	Ret Addr

Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB
x6FFC
x6FFD
x6FFE
x6FFF
x7000

x4004	69	x0045	← Head
x4005	16390	x4006	
x4006	67	x0043	R6 →
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	R5 →
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

```

;
;;
T
LDR R7, R5, #2 ;Restore return address

```

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1	R5	R7
69	x4006	CFP	Ret Addr

Runtime stack

...
x6FF5
x6FF6
x6FF7
x6FF8
x6FF9
x6FFA
x6FFB Ret Val
x6FFC x4006
x6FFD CFP
x6FFE Ret Addr
x6FFF Ret Val
x7000 x4004

x4004	69	x0045	← Head
x4005	16390	x4006	
x4006	67	x0043	
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	R5 →
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

R6 →

R5 →

```

LDR R5, R5, #1 ;Restore old frame pointer

```

```

typedef struct Node{
    char symbol;
    struct Node *next;
}node;

void print_list(node *cursor){
    if (cursor==NULL)
        /* List empty; do nothing */
        return;
    else{
        /* Print and recurse */
        printf("%c", cursor->symbol);
        print_list(cursor->next);
    }
}

```

Printing a linked list

R0	R1	R5	R7
69	x4006	CFP	Ret Addr

```

;print_list(head->next);

```

```

ADD R6, R6, #-1

ADD R6, R6, #-1
JSR PRINT_LIST

```

```

;skip here if head is null
;;Part 3 - callee tear down (preparing to return)
TEAR_DOWN

```

```

ADD R6, R6, #2
RET

```

```

.END

```

x4004	69	x0045	← Head
x4005	16390	x4006	
x4006	67	x0043	
x4007	16392	x4008	
x4008	69	x0045	
x4009	16394	x400A	R5 →
x400A	50	x0032	
x400B	16396	x400C	
x400C	50	x0032	
x400D	16398	x400E	
x400E	48	x0030	
...	

R6 →

Runtime stack

...	
x6FF5	
x6FF6	
x6FF7	
x6FF8	
x6FF9	
x6FFA	
x6FFB	Ret Val
x6FFC	x4006
x6FFD	CFP
x6FFE	Ret Addr
x6FFF	Ret Val
x7000	x4004

Linked Lists Practice

More linked lists

- Exercise(s)
 - Given two already sorted linked lists, merge them.
 - Reverse a singly linked list.
 - Implement a doubly linked list.

Sorted merging - election day special

- Given two lists of commanders-in-chiefs, merge the list while maintaining their sorted property
 - (Reagan, 1911) -> (Nixon, 1913) -> (Trump, 1946) -> (Bush, 1946) -> NULL
 - (Carter, 1924) -> (Biden, 1942) -> (Clinton, 1946) -> (Obama, 1961) -> NULL
- What should the merged list look like?

```
typedef struct person{
    char *name;
    unsigned int byear;
    struct person *next;
}node;
```

[Git Link](#)

Reverse a singly-linked list

- Given the list, generate a *new* (not just print) linked list where the nodes are linked in *reverse* order.
 - (Reagan, 1911)->(Nixon, 1913)->(Carter, 1924)->(Biden, 1942)->(Trump, 1946)->(Bush, 1946)->(Clinton, 1946)->(Obama, 1961)->NULL
 - (Obama, 1961)->(Clinton, 1946)->(Bush, 1946)->(Trump, 1946)->(Biden, 1942)->(Carter, 1924)->(Nixon, 1913)->(Reagan, 1911)->NULL

[Git Link](#)

Doubly linked lists

- How many pointers to maintain?
 - Head pointer? Tail pointer?



- How should insertion work?

- At head, middle, tail.

- How should deletion work? **Left as exercise!**

- From head, middle, tail.

```
typedef struct person{
    char *name;
    struct person *next;
    struct person *prev;
}node;
```

[Git Link](#)

More practice? Okey doke!

More practice? Okey doke!

- Practicing on linked lists:

More practice? Okey doke!

- Practicing on linked lists:
 - Stanford's [Linked List Question Bank](#)

More practice? Okey doke!

- Practicing on linked lists:
 - Stanford's [Linked List Question Bank](#)
 - Also good practice for technical interviews!