Linear Collections: Linked Lists

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Outline

Linked List Implementations

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Contents

- Linked Data Structures
- Singly Linked Lists
  - node class implementation
- Doubly Linked Lists
  - node class extension
- Implementations
- Choosing Collection Implementations

The Problems with Arrays were

- Contiguous Memory
- Physically Adjacent Cells
- One-to-One Correspondence between logical position of an item and its Physical position in memory
  - $\Rightarrow$ decouple logical and physical position
  - $\Rightarrow$ no shifting of items required

Linked Data Structures

- Consist of Nodes
- One Node per item
- Each Node consists of
  - the actual data
  - one or more links to other Nodes

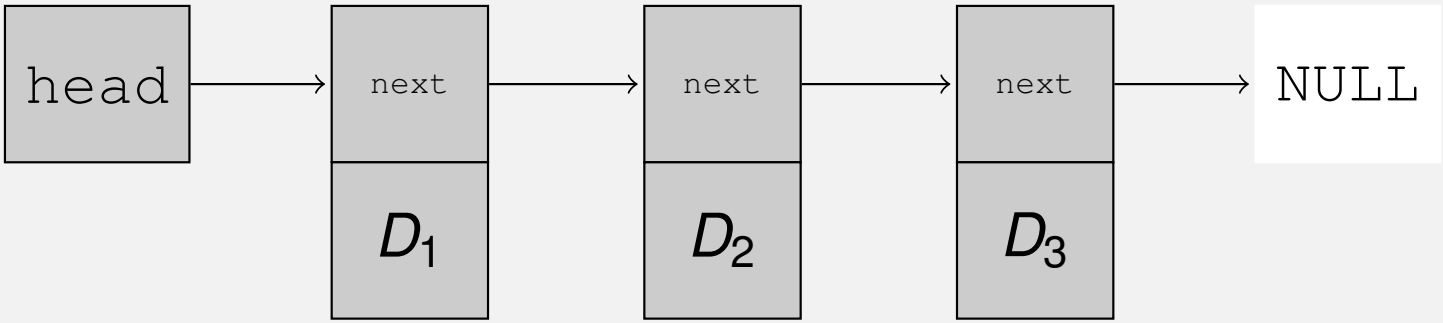
  → link, pointer, and reference are synonymous in this Context

Singly Linked Lists

Singly Linked Lists

Singly Linked Lists

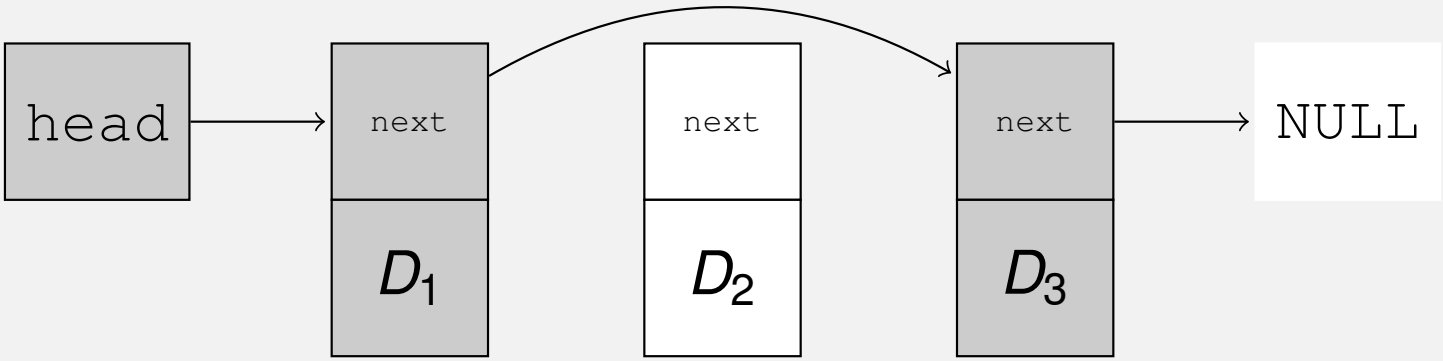
- Each Node has 1 Successor:



- External Head Pointer
  - Points to first Node
- Node Access
  - Traverse the pointers starting from the Head

Changing Items

- To Add or Delete an Entry



- Shuffle Around only Pointers
- Data remain at their original memory locations
- Free memory only if no longer referenced

The Cost

- Linear Searches
  - Required by (almost) all operations
  - *“Intrinsic O(n) overhead”*
- Cache Some Pointers
  - Reduces some operations to O(1)
  - Maintain a second, external tail pointer
  - Keep pointer to “interesting” nodes

  $\Rightarrow$ Still doesn’t help in all cases!

A Node Class Interface in Objective-C

Example (usually a *private inner class*)

```
@interface SNode:  NSObject
{
        SNode   *next;                  // pointer to next Node
        id      data;                   // data contents
}

- initWithData:  d next:  (SNode *) n;    // constructor

- data;                                  // data getter

- setData:  newData;                     // data setter

- (SNode *) next;                        // next node getter

- setNext:  (SNode *) newNext;           // next node setter

@end
```

A Node Class Implementation in Objective-C

Example

```
@implementation SNode

- initWithData:  d next:  (SNode *) n                    // constructor
{
        return [[[self init] setData:  d] setNext:  n];   // init and set data/link
}

- (SNode *) next         { return next; }                // next node getter

- setNext:  (SNode *) newNext                             // next node setter
                         { next = newNext; return self; }

- data                   { return data; }                // data getter

- setData:  newData                                       // data setter
{
        if (data != newData)                             // is there a change?
        {
                [data release];                          // release old data
                data = [newData retain];                 // retain new data
        }
        return self;
}
@end
```

A Node Class in C++

Example (usually a *private inner class*)

```
template <class T> class SNode
{
        SNode   *nxt;                   // pointer to next Node
        T        dta;                   // data contents

public:
        SNode(T &d, SNode *n = NULL)    // constructor
        {
                nxt = n;                // set next node
                dta = d;                // and data
        }

        T data() { return dta; }        // data getter

        void setData(T &d) { dta = d; } // data setter

        SNode *next() { return nxt; }   // next node getter

        void setNext(SNode<T> *n)       // next node setter
        {
                nxt = n;
        }
};
```

Creating the first Node

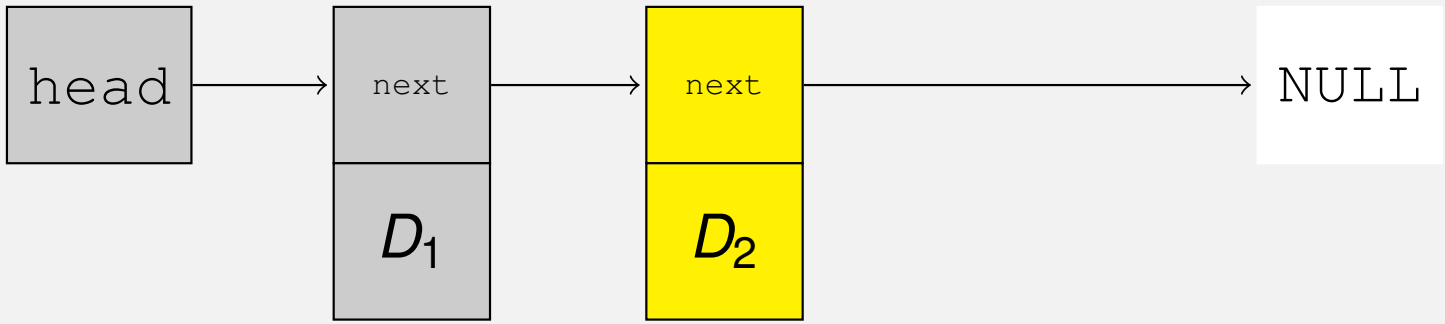
Example (Objective-C)

```
SNode *head = [[SNode alloc]
              initWithData: @"D1" next: nil];
```

Example (C++)

```
string d1("D1");
SNode<string> *head = new SNode<string>(d1);
```

Linking a Second Node



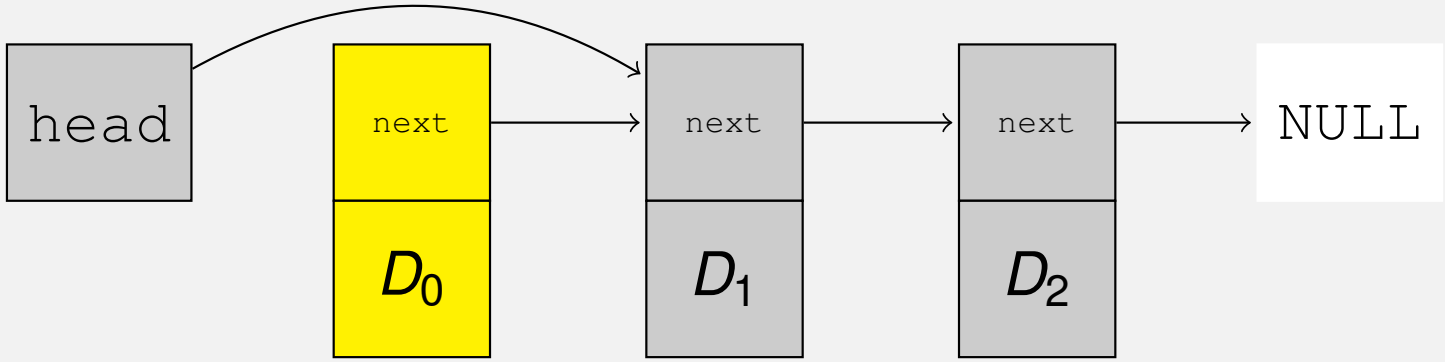
Example (Objective-C)

```
[head setNext:  [[SNode alloc]
                initWithData:  @"D2" next:  nil]];
```

Example (C++)

```
string d2("D2");
          head->setNext(new SNode<string>(d2));
```

Linking a Node to the Head



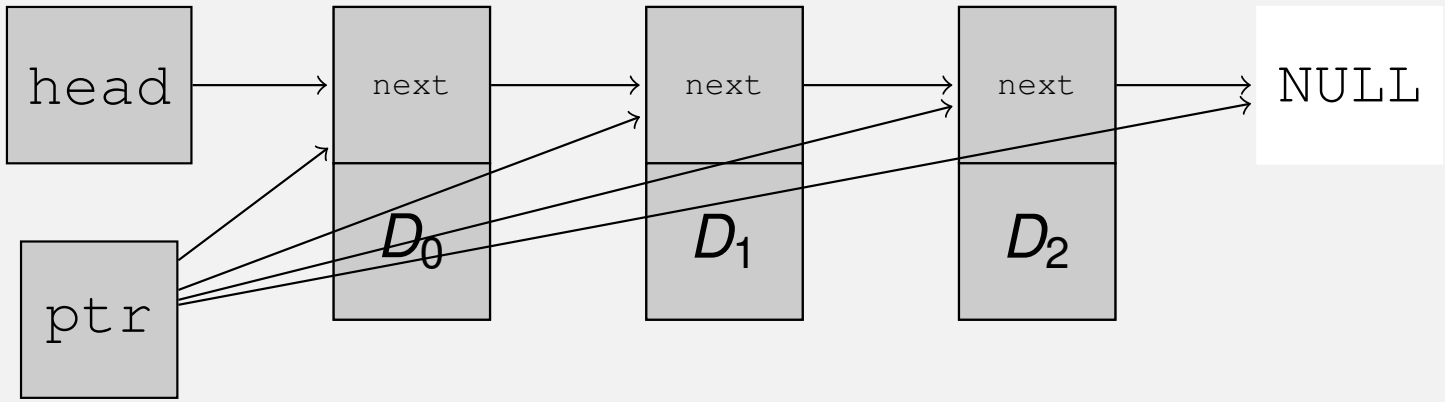
Example (Objective-C)

```
head = [[SNode alloc]
            initWithData:  @"D0" next:  head];
```

Example (C++)

```
string d0("D0");
            head = new SNode<string>(d0, head);
```

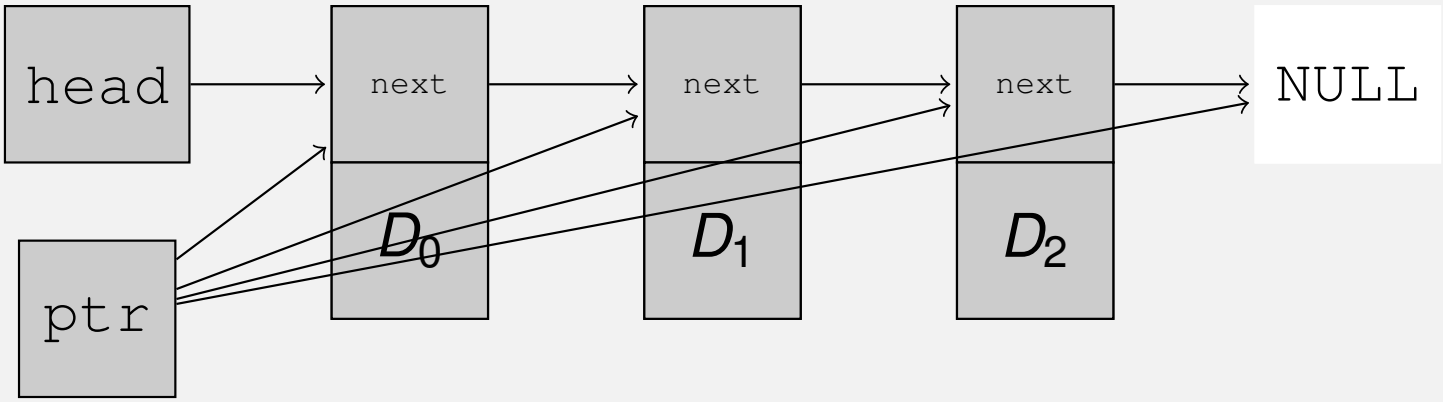
Traversing a Linked Structure (`while`)



Example (using a `while` loop in Objective-C)

```
SNode *ptr = head;                  // first element
while (ptr != nil)                  // as long as node is valid
{                                   // do something useful with the data:
        printf("ptr:  %s\n", [[[ptr data] description] UTF8String]);
        ptr = [ptr next];           // next element
}
```

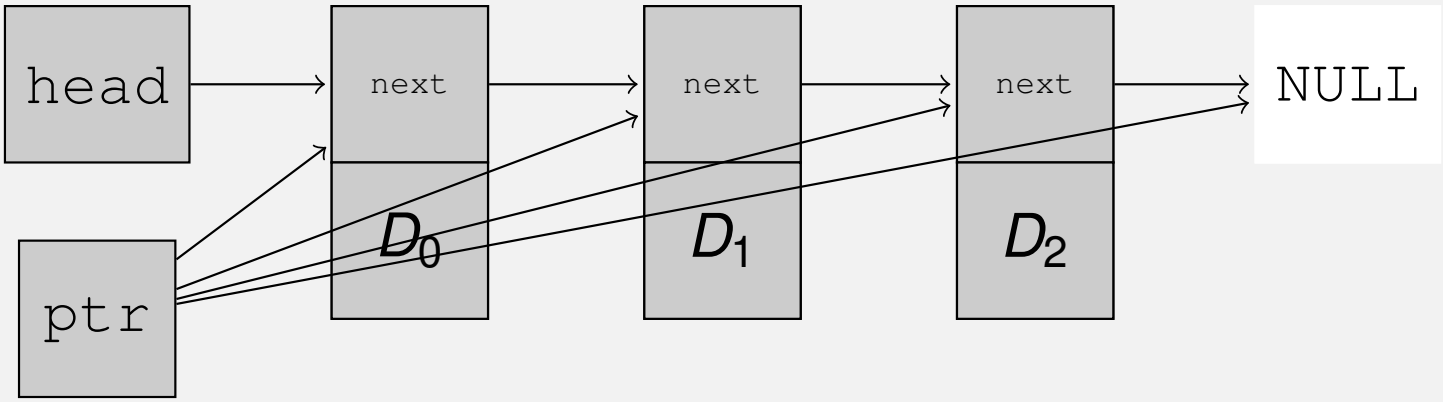
Traversing a Linked Structure (`for`)



Example (using a `for` loop in Objective-C)

```
for (SNode *ptr = head; // first element
     ptr != nil;        // until finished
     ptr = [ptr next])  // switch to next element
{
    printf("ptr:  %s\n", [[[ptr data] description] UTF8String]);
}
```

Traversing a Linked Structure (C++)



Example (using a `for` loop in C++)

```
for (SNode<string> *ptr = head; // first element
     ptr != NULL;               // until finished
     ptr = ptr->next())         // switch to next element
{
    cout << "ptr:  "<< ptr->data() << endl;
}
```

Inserting Anywhere

- Traverse to specific Node — O(n)
- Save where that Node Points to — O(1)
- Let Node point to new Node — O(1)
- Copy saved pointer to new Node (`nil` if at the end) — O(1)

→ Complexity: O(n)

Delete First Node

- Point Head to second Node, only then free memory!

```
SNode *oldHead = head;
head = [head next];
[oldHead release];
```

- Complexity: O(1)

Deleting Anywhere

- Traverse to specific node $O(n)$
- Let Predecessor of that Node point to the successor of the Node $O(1)$
- Free the Node's memory $O(1)$

$\rightarrow$ Complexity: $O(n)$

Caveats

- `NULL` Pointer Exceptions
- Whenever you use a pointer w/o checking, e.g.

```
head = head->next->next;

head = [SNode new];
head->data = data;
```

- Results in exceptions or program crashes!
  - ⇒ always check pointers!
- `nil` method invocations are safe in Objective-C!
  - ⇒ `[head next]` better than `head->next`
  - ⇒ safer to use access methods than directly using instance variables!

Pros and Cons of Singly Linked Lists

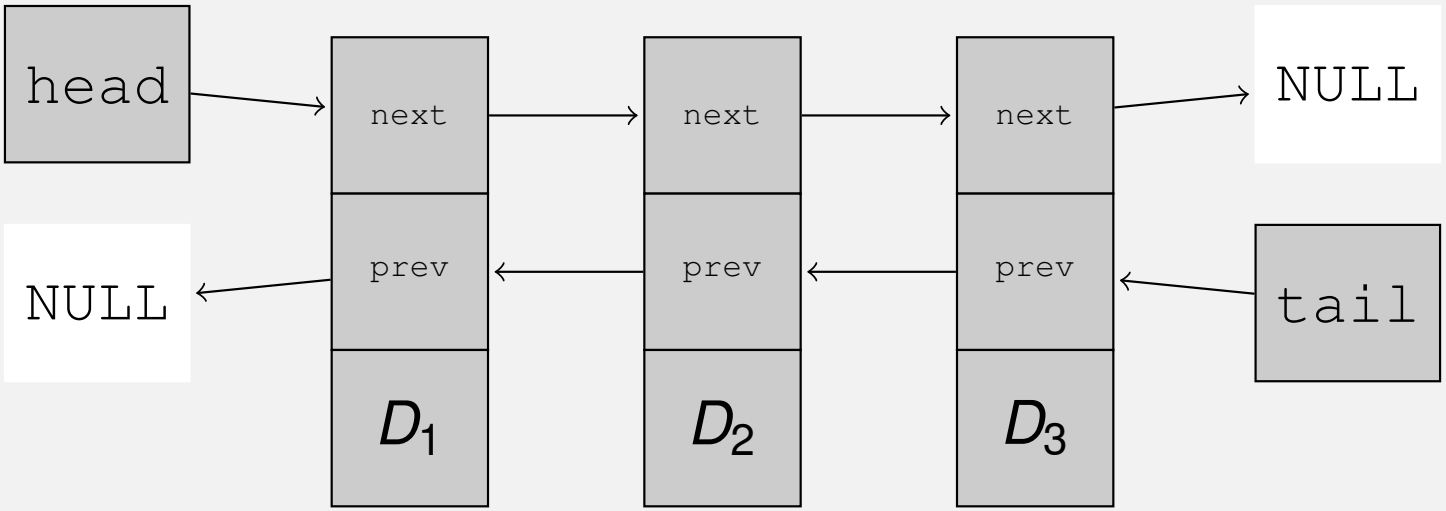
+ First Item Insertion/Removal: O(1)
+ Dynamic Memory Allocation
+ No Resizing Overhead
– Memory-Overhead for Pointers
– Most Operations are O(n)
– Costly Binary Search O($n \log n$)
  $\Rightarrow$ binary search more expensive than linear search

Doubly Linked Lists

Doubly Linked Lists

Doubly Linked Lists

- Add Link to Predecessor Node:



- Traversal in both directions
- Easy moving from a given Node to both its successor (next node) and predecessor (previous node)

Node Class Extension in Objective-C

Example (usually a *private inner class*)

```
@interface DNode:  SNode                    // extend SNode
{
        DNode   *prev;                       // pointer to previous Node
}

- initWithData:  d                           // constructor
          next:  (DNode *) n                 // takes both the successor (next)
          prev:  (DNode *) p;                // and predecessor (prev)

- (DNode *) prev;                           // predecessor node getter

- setPrev:  (DNode *) newPrev;              // predecessor node setter

@end
```

DNode Class Implementation in Objective-C

Example

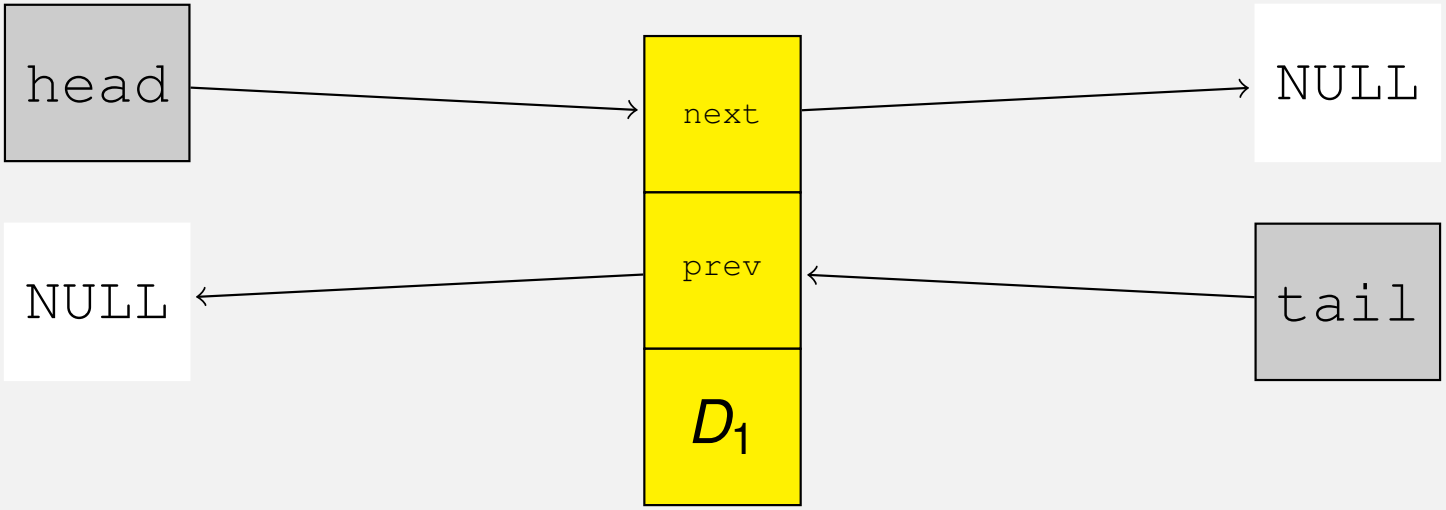
```
@implementation DNode

- initWithData:  d next:  (DNode *) n prev:  (DNode *) p   // constructor
{                                                          // init and set data/links
        return [[self initWithData:  d next:  n] setPrev:  p];
}

- (DNode *) prev                                          // predecessor node getter
{
        return prev;
}

- setPrev:  (DNode *) newPrev                             // predecessor node setter
{
        prev = newPrev;
        return self;
}

@end
```

DNode Class in C++

Example (usually a *private inner class*)

```
template <class T> class DNode:  public SNode<T>
{
        DNode<T>        *pre;                    // pointer to previous Node

public:
        DNode(T &d, DNode *n = NULL, DNode *p = NULL): SNode<T>(d, n)
        {
                pre = p;                         // set predecessor node
        }

        DNode *prev() { return pre; }           // prev node getter
        DNode *next()                            // next node getter
        { return (DNode *) SNode<T>::next(); }  // use super class getter

        void setPrev(DNode *p) { pre = p; }     // prev node setter
};
```

Creating A Doubly Linked Node



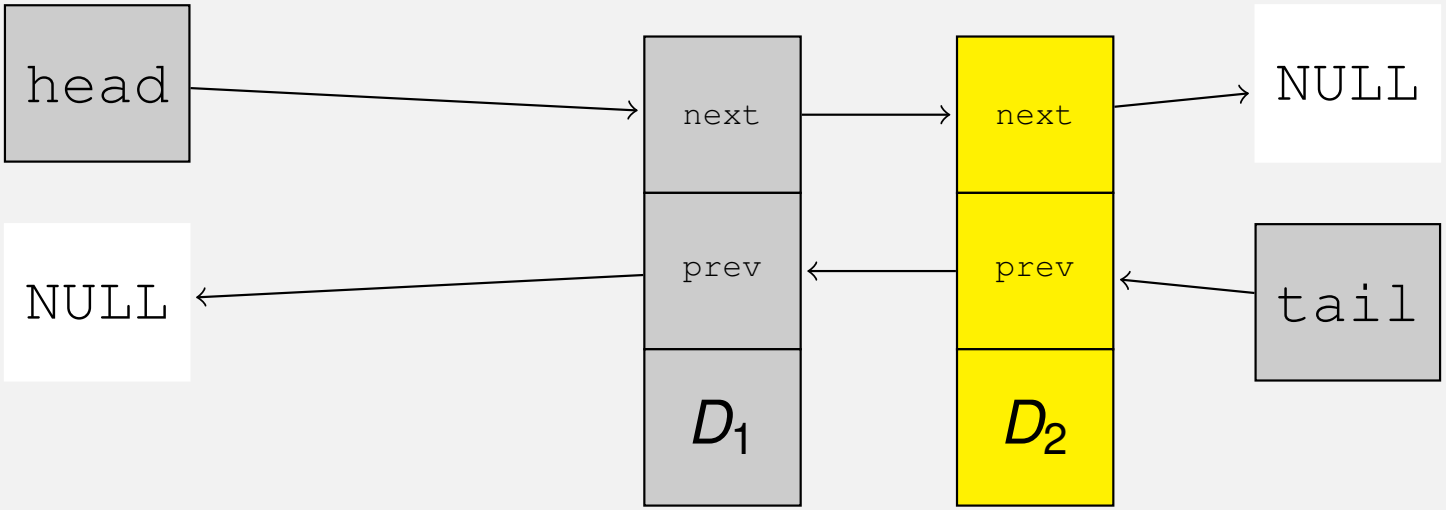
Example (Objective-C)

```
DNode *head = [[DNode alloc] initWithData: @"D1" next: nil prev: nil];

DNode *tail = head;
```

Example (C++)

```
string d1("D1");
DNode<string> *head = new DNode<string>(d1);

DNode<string> *tail = head;
```

Linking a Second DNode



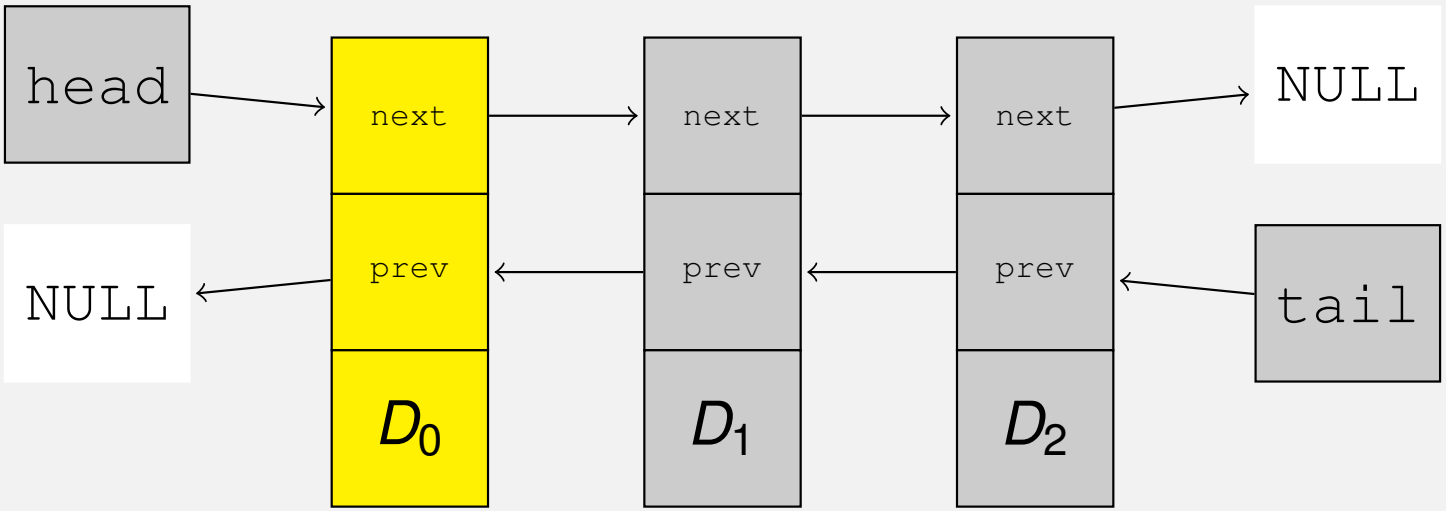
Example (Objective-C)

```
[head setNext:  [[DNode alloc] initWithData: @"D2" next: nil prev: head]];

tail = [tail next];
```

Example (C++)

```
string d2("D2");
head->setNext(new DNode<string>(d2,NULL,head));

tail = tail->next();
```

Inserting a DNode at the Head



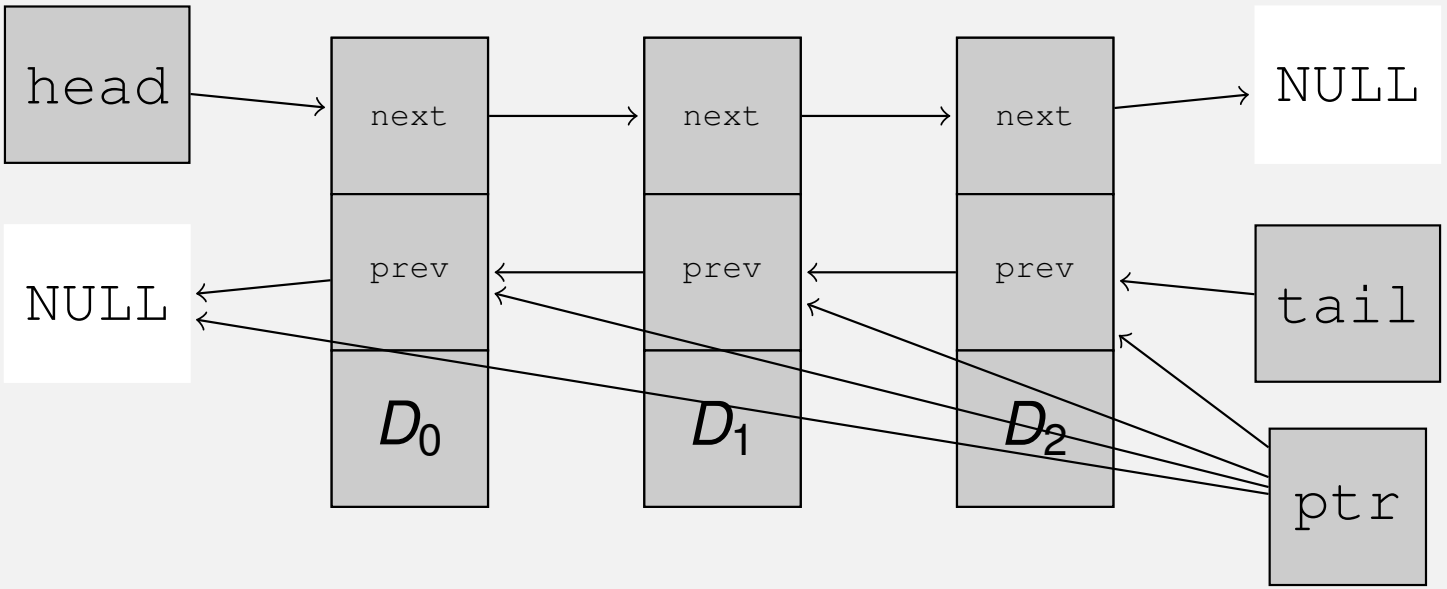
Example (Objective-C)

```
[head setPrev:  [[DNode alloc] initWithData: @"D2" next: head prev: nil]];

head = [head prev];
```

Example (C++)

```
string d2("D2");
head->setPrev(new DNode<string>(d2, head));

head = head->prev();
```

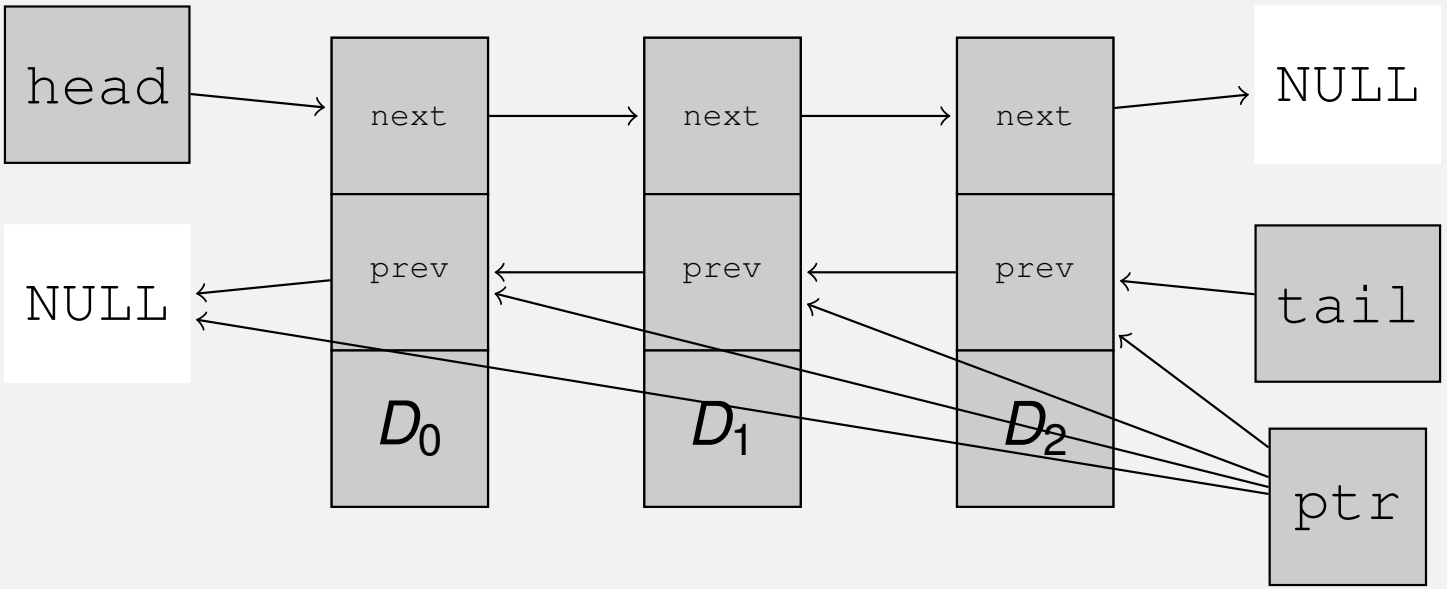
Traversing Backwards



Example (using a `for` loop in Objective-C)

```
for (DNode *ptr = tail; // last element
     ptr != nil;        // until finished
     ptr = [ptr prev])  // switch to predecessor element
{
    printf("ptr:  %s\n", [[[ptr data] description] UTF8String]);
}
```

Traversing Backwards (C++)



Example (using a `for` loop in C++)

```
for (DNode<string> *ptr = tail; // last element
     ptr != NULL;               // until finished
     ptr = ptr->prev())         // switch to predecessor element
{
    cout << "ptr:  "<< ptr->data() << endl;
}
```

Caveats

- `NULL` Pointer Exceptions
  - if anything, the number of checks now has increased
  - `head` and `tail` as well as `prev` and `next` for every node!

  $\Rightarrow$ more `if`'s required for correct code

Circular Linked Lists

Circular Lists

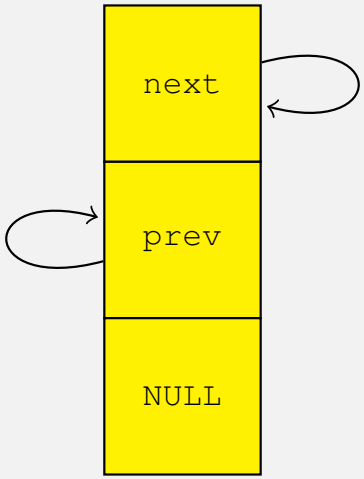
Circular Lists

- Problem: `head` and `tail`
  - extra variables
- Special Cases
  - inserting/deleting at the beginning/end
- Solution
  - use a dummy Node

  → `next` points to first List element, like head

  → `prev` points to last List element, like tail

Empty Circular List



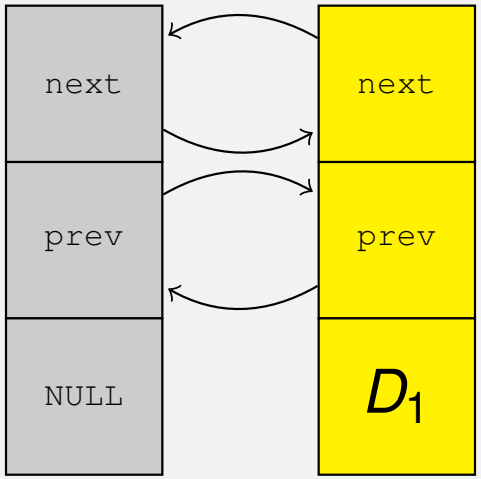
Example (Objective-C)

```
DNode *list = [DNode new];
[list setNext:  list];
[list setPrev:  list];
```

Example (C++)

```
string dummy("");
DNode<string> *list = new DNode<string>(dummy);

list->setNext(list); list->setPrev(list);
```

Adding at the Head



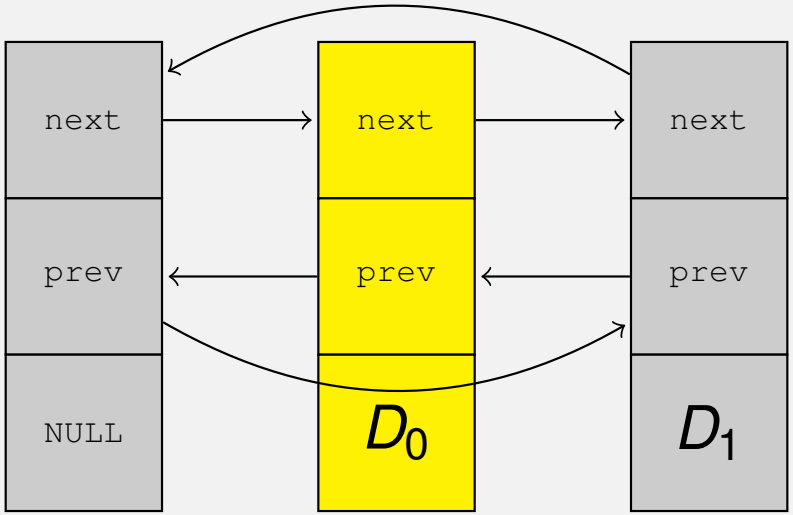
Example (Objective-C)

```
DNode *node = [[DNode alloc] initWithData:  @"D1" next: [list next] prev: list];
[[list next] setPrev: node];

[list setNext: node];
```

Example (C++)

```
DNode<string> *node = new DNode<string>(d1, list->next(), list);
list->next()->setPrev(node);

list->setNext(node);
```

Adding at the Head (2)



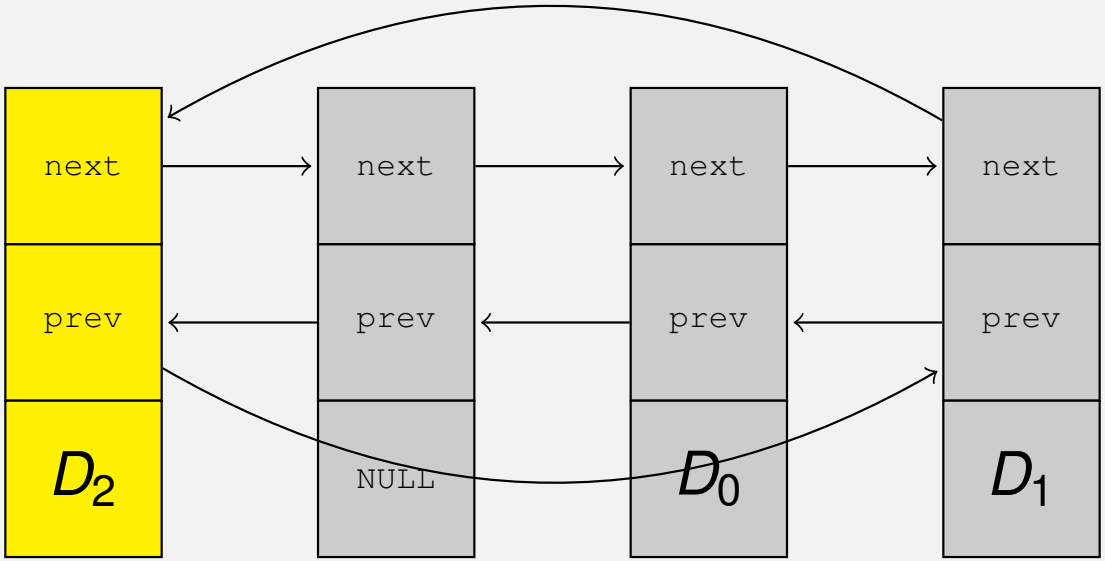
Example (Objective-C)

```
DNode *node = [[DNode alloc] initWithData:  @"D0" next: [list next] prev: list];
[[list next] setPrev: node];

[list setNext: node];
```

Example (C++)

```
DNode<string> *node = new DNode<string>(d0, list->next(), list);
list->next()->setPrev(node);

list->setNext(node);
```

Adding at the Tail



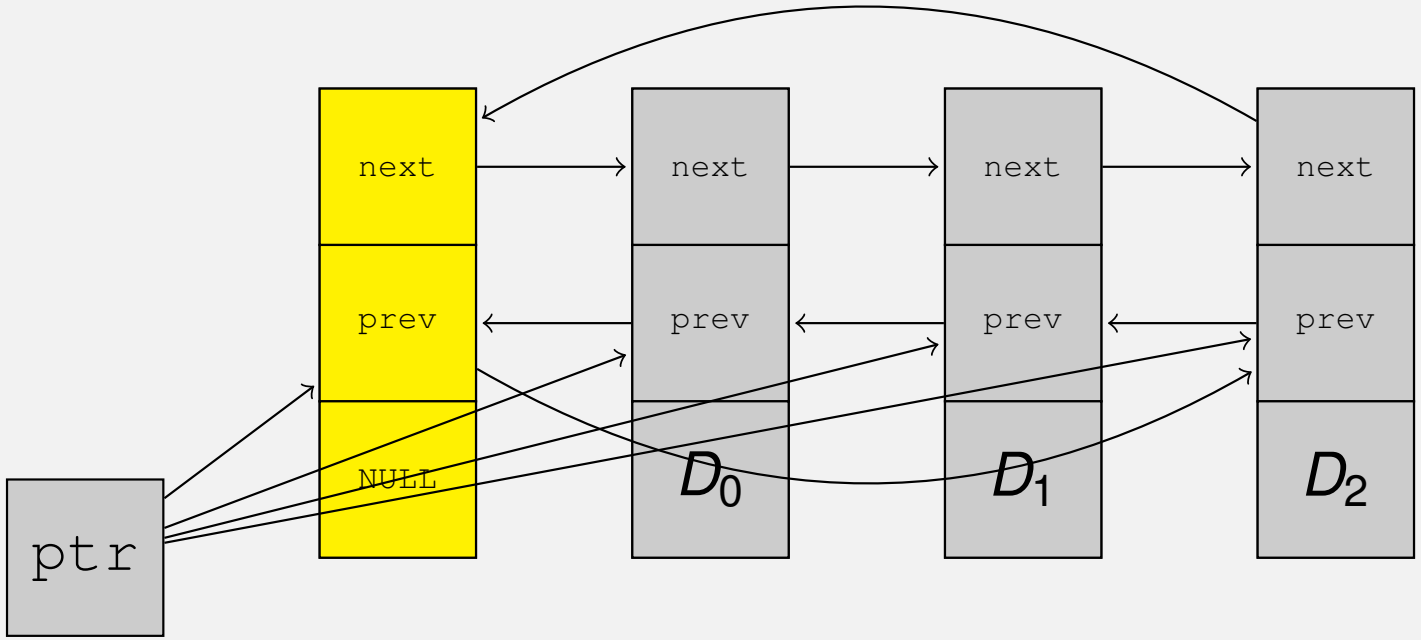
Example (Objective-C)

```
node = [[DNode alloc] initWithData: @"D2" next: list prev: [list prev]];

[[list prev] setNext:  node]; [list setPrev:  node];
```

Example (C++)

```
DNode<string> *node = new DNode<string>(d2, list, list->prev());

list->prev()->setNext(node); list->setPrev(node);
```

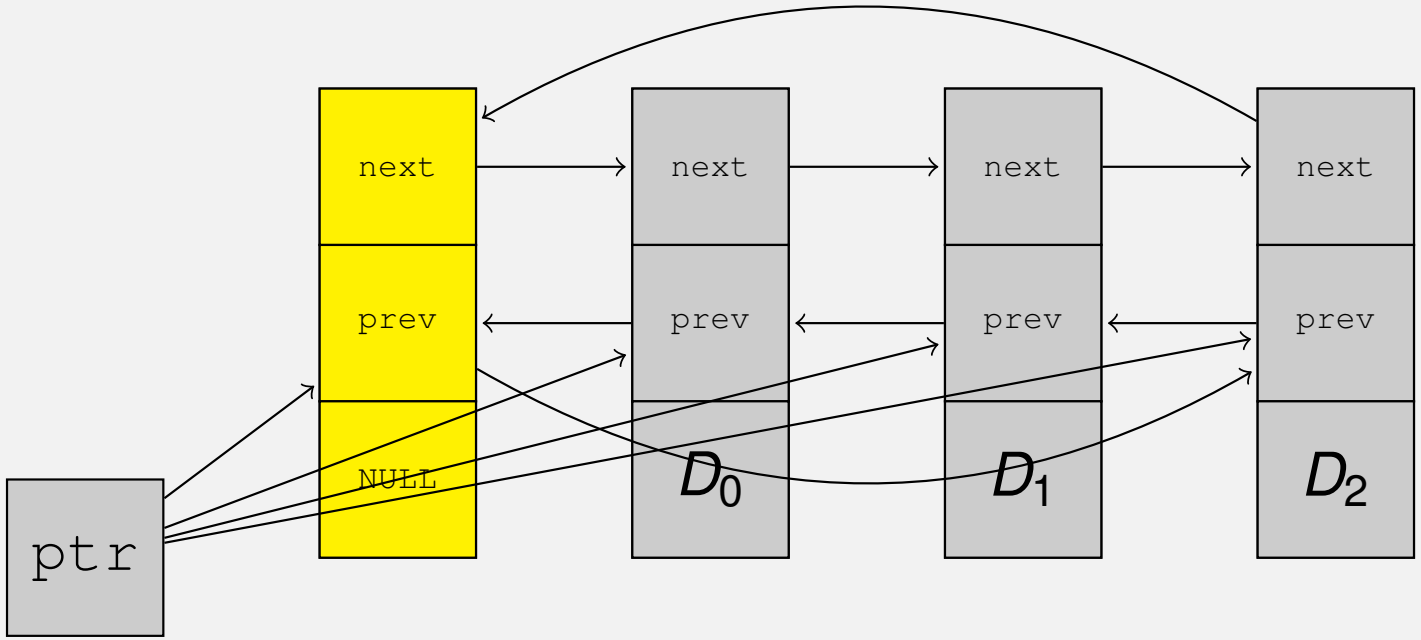
Traversing Circular Lists



Example (using a `for` loop in Objective-C)

```
for (DNode *ptr = [list next];   // first element
     [ptr data] != nil;          // until finished
     ptr = [ptr next])           // switch to successor element
{
    printf("ptr:  %s\n", [[[ptr data] description] UTF8String]);
}
```

Traversing Circular Lists (C++)



Example (using a `for` loop in C++)

```
for (DNode<string> *ptr = list->next(); // first element
     ptr->data() != dummy;              // until finished
     ptr = ptr->next())                 // switch to successor element
{
    cout << "ptr:  "<< ptr->data() << endl;
}
```