

# Linked Lists

Victor Milenkovic

Department of Computer Science  
University of Miami

CSC220 Programming II – Fall 2015



# Outline

# Arrays are slow

# Arrays are slow

- ▶ Speed of SortedPD addOrChangeEntry:



# Arrays are slow

- ▶ Speed of SortedPD addOrChangeEntry:
  - ▶ The find method for SortedPD is  $O(\log n)$ .



# Arrays are slow

- ▶ Speed of SortedPD addOrChangeEntry:
  - ▶ The find method for SortedPD is  $O(\log n)$ .
  - ▶ addOrChangeEntry must also remove the entry at the index  $i$  returned by find.



# Arrays are slow

- ▶ Speed of SortedPD addOrChangeEntry:
  - ▶ The find method for SortedPD is  $O(\log n)$ .
  - ▶ addOrChangeEntry must also remove the entry at the index  $i$  returned by find.
  - ▶ Move all the entries from  $i + 1$  to size  $- 1$ .



# Arrays are slow

- ▶ Speed of SortedPD addOrChangeEntry:
  - ▶ The find method for SortedPD is  $O(\log n)$ .
  - ▶ addOrChangeEntry must also remove the entry at the index  $i$  returned by find.
  - ▶ Move all the entries from  $i + 1$  to size  $- 1$ .
  - ▶ That takes  $O(n)$ , which dominates the running time.





# Arrays are slow

- ▶ Speed of SortedPD addOrChangeEntry:
  - ▶ The find method for SortedPD is  $O(\log n)$ .
  - ▶ addOrChangeEntry must also remove the entry at the index  $i$  returned by find.
  - ▶ Move all the entries from  $i + 1$  to size  $- 1$ .
  - ▶ That takes  $O(n)$ , which dominates the running time.
  - ▶ No hope of a fast addOrChange method for large  $n$ .



# Linked List

# Linked List

- ▶ Double Linked List



# Linked List

- ▶ Double Linked List
  - ▶ A different way of storing a list.



# Linked List

- ▶ Double Linked List
  - ▶ A different way of storing a list.
  - ▶ Allows us to add or remove an entry in  $O(1)$  time.



# Linked List

- ▶ Double Linked List
  - ▶ A different way of storing a list.
  - ▶ Allows us to add or remove an entry in  $O(1)$  time.
- ▶ The **DLLNode** class.



# Linked List

- ▶ Double Linked List
  - ▶ A different way of storing a list.
  - ▶ Allows us to add or remove an entry in  $O(1)$  time.
- ▶ The **DLLNode class**.
  - ▶ Extends prog02.DirectoryEntry.



# Linked List

- ▶ Double Linked List
  - ▶ A different way of storing a list.
  - ▶ Allows us to add or remove an entry in  $O(1)$  time.
- ▶ The **DLLNode** class.
  - ▶ Extends prog02.DirectoryEntry.
  - ▶ Adds next and previous field





# Linked List

- ▶ Double Linked List
  - ▶ A different way of storing a list.
  - ▶ Allows us to add or remove an entry in  $O(1)$  time.
- ▶ The **DLLNode** class.
  - ▶ Extends prog02.DirectoryEntry.
  - ▶ Adds next and previous field
  - ▶ with get and set methods.



# Linked List

- ▶ Double Linked List
  - ▶ A different way of storing a list.
  - ▶ Allows us to add or remove an entry in  $O(1)$  time.
- ▶ The **DLLNode class**.
  - ▶ Extends prog02.DirectoryEntry.
  - ▶ Adds next and previous field
  - ▶ with get and set methods.
  - ▶ References to the next and previous entries in the list.



No array needed

## No array needed

- ▶ So we don't need an array anymore.



## No array needed

- ▶ So we don't need an array anymore.
- ▶ All we need is a reference to any element of the list



## No array needed

- ▶ So we don't need an array anymore.
- ▶ All we need is a reference to any element of the list
  - ▶ Call getNext() or getPrevious() repeatedly.



## No array needed

- ▶ So we don't need an array anymore.
- ▶ All we need is a reference to any element of the list
  - ▶ Call getNext() or getPrevious() repeatedly.
  - ▶ Get to any other element.



## No array needed

- ▶ So we don't need an array anymore.
- ▶ All we need is a reference to any element of the list
  - ▶ Call getNext() or getPrevious() repeatedly.
  - ▶ Get to any other element.
- ▶ For convenience, it is customary to store references to





## No array needed

- ▶ So we don't need an array anymore.
- ▶ All we need is a reference to any element of the list
  - ▶ Call getNext() or getPrevious() repeatedly.
  - ▶ Get to any other element.
- ▶ For convenience, it is customary to store references to
  - ▶ **head**, the first entry in the list



## No array needed

- ▶ So we don't need an array anymore.
- ▶ All we need is a reference to any element of the list
  - ▶ Call getNext() or getPrevious() repeatedly.
  - ▶ Get to any other element.
- ▶ For convenience, it is customary to store references to
  - ▶ **head**, the first entry in the list
  - ▶ **tail**, the last entry in the list



## No array needed

- ▶ So we don't need an array anymore.
- ▶ All we need is a reference to any element of the list
  - ▶ Call getNext() or getPrevious() repeatedly.
  - ▶ Get to any other element.
- ▶ For convenience, it is customary to store references to
  - ▶ **head**, the first entry in the list
  - ▶ **tail**, the last entry in the list
- ▶ The **slides** show how to use this structure to implement a phone directory.



# Finding a name

## Finding a name

- ▶ To find Ian, we need to look at each entry.



## Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.



# Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?



# Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.





# Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)



# Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)
- ▶ That's not the one we want,



# Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)
- ▶ That's not the one we want,
  - ▶ so we need to move entry forward one.



# Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)
- ▶ That's not the one we want,
  - ▶ so we need to move entry forward one.
  - ▶ The only way to change the value of entry is an assignment



# Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)
- ▶ That's not the one we want,
  - ▶ so we need to move entry forward one.
  - ▶ The only way to change the value of entry is an assignment
  - ▶ entry =



# Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)
- ▶ That's not the one we want,
  - ▶ so we need to move entry forward one.
  - ▶ The only way to change the value of entry is an assignment
  - ▶ entry =
  - ▶ What do we set entry equal to?



# Finding a name

- ▶ To find Ian, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)
- ▶ That's not the one we want,
  - ▶ so we need to move entry forward one.
  - ▶ The only way to change the value of entry is an assignment
  - ▶ entry =
  - ▶ What do we set entry equal to?
- ▶ The loop should return when it finds Ian,



# Finding a name

- ▶ To find lan, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)
- ▶ That's not the one we want,
  - ▶ so we need to move entry forward one.
  - ▶ The only way to change the value of entry is an assignment
  - ▶ entry =
  - ▶ What do we set entry equal to?
- ▶ The loop should return when it finds lan,
  - ▶ but what if lan is not there?





# Finding a name

- ▶ To find lan, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)
- ▶ That's not the one we want,
  - ▶ so we need to move entry forward one.
  - ▶ The only way to change the value of entry is an assignment
  - ▶ entry =
  - ▶ What do we set entry equal to?
- ▶ The loop should return when it finds lan,
  - ▶ but what if lan is not there?
  - ▶ What will stop the loop?



# Finding a name

- ▶ To find lan, we need to look at each entry.
  - ▶ Set the variable entry to the first one.
  - ▶ How do we do that?
  - ▶ Compare the name at entry to the name we are looking for.
  - ▶ How do we get the name at entry? (Jay)
- ▶ That's not the one we want,
  - ▶ so we need to move entry forward one.
  - ▶ The only way to change the value of entry is an assignment
  - ▶ entry =
  - ▶ What do we set entry equal to?
- ▶ The loop should return when it finds lan,
  - ▶ but what if lan is not there?
  - ▶ What will stop the loop?
  - ▶ What value of entry tells us that we have seen everything in the list?



## Removing an entry

## Removing an entry

- ▶ `removeEntry`

## Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?
- ▶ Next removeEntry must tell Zoe's entry to use Ann's entry as its next entry.





## Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?
- ▶ Next removeEntry must tell Zoe's entry to use Ann's entry as its next entry.
  - ▶ What method sets Zoe's next entry pointer?



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?
- ▶ Next removeEntry must tell Zoe's entry to use Ann's entry as its next entry.
  - ▶ What method sets Zoe's next entry pointer?
  - ▶ How do we invoke it?



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?
- ▶ Next removeEntry must tell Zoe's entry to use Ann's entry as its next entry.
  - ▶ What method sets Zoe's next entry pointer?
  - ▶ How do we invoke it?
  - ▶ What value do we give it?



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?
- ▶ Next removeEntry must tell Zoe's entry to use Ann's entry as its next entry.
  - ▶ What method sets Zoe's next entry pointer?
  - ▶ How do we invoke it?
  - ▶ What value do we give it?
  - ▶ Similarly Ann's must point back to Zoe's.



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?
- ▶ Next removeEntry must tell Zoe's entry to use Ann's entry as its next entry.
  - ▶ What method sets Zoe's next entry pointer?
  - ▶ How do we invoke it?
  - ▶ What value do we give it?
  - ▶ Similarly Ann's must point back to Zoe's.
- ▶ At this point Ian thinks he is still in the list,



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?
- ▶ Next removeEntry must tell Zoe's entry to use Ann's entry as its next entry.
  - ▶ What method sets Zoe's next entry pointer?
  - ▶ How do we invoke it?
  - ▶ What value do we give it?
  - ▶ Similarly Ann's must point back to Zoe's.
- ▶ At this point Ian thinks he is still in the list,
  - ▶ but he really isn't.



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?
- ▶ Next removeEntry must tell Zoe's entry to use Ann's entry as its next entry.
  - ▶ What method sets Zoe's next entry pointer?
  - ▶ How do we invoke it?
  - ▶ What value do we give it?
  - ▶ Similarly Ann's must point back to Zoe's.
- ▶ At this point Ian thinks he is still in the list,
  - ▶ but he really isn't.
  - ▶ Everyone is ignoring him!



# Removing an entry

- ▶ removeEntry
  - ▶ calls find("Ian") to find its entry in the list.
  - ▶ Then it sets variables next and previous.
  - ▶ How does it set them?
- ▶ Next removeEntry must tell Zoe's entry to use Ann's entry as its next entry.
  - ▶ What method sets Zoe's next entry pointer?
  - ▶ How do we invoke it?
  - ▶ What value do we give it?
  - ▶ Similarly Ann's must point back to Zoe's.
- ▶ At this point Ian thinks he is still in the list,
  - ▶ but he really isn't.
  - ▶ Everyone is ignoring him!
  - ▶ Similar to entries in array with index bigger than size.





# Adding Ian

## Adding Ian

- ▶ How do we add Ian back again?



# Adding Ian

- ▶ How do we add Ian back again?
  - ▶ Let's just put him at the end.



# Adding Ian

- ▶ How do we add Ian back again?
  - ▶ Let's just put him at the end.
  - ▶ Three values have to change for this to happen.



# Adding Ian

- ▶ How do we add Ian back again?
  - ▶ Let's just put him at the end.
  - ▶ Three values have to change for this to happen.
  - ▶ Which values?



# Adding Ian

- ▶ How do we add Ian back again?
  - ▶ Let's just put him at the end.
  - ▶ Three values have to change for this to happen.
  - ▶ Which values?
  - ▶ How do we set them?



# Adding Ian

- ▶ How do we add Ian back again?
  - ▶ Let's just put him at the end.
  - ▶ Three values have to change for this to happen.
  - ▶ Which values?
  - ▶ How do we set them?
  - ▶ To what?



## SortedDLLPD find and addOrChangeEntry



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put Ian if he is not there.



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.
  - ▶ How does it know it has reached this entry?



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put Ian if he is not there.
  - ▶ In that case it returns the entry after Ian.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put Ian if he is not there.
  - ▶ In that case it returns the entry after Ian.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?
- ▶ SortedDLLPD addOrChangeEntry uses the output of find.



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?
- ▶ SortedDLLPD addOrChangeEntry uses the output of find.
  - ▶ It sets the variable next to the entry that should be next after lan.



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?
- ▶ SortedDLLPD addOrChangeEntry uses the output of find.
  - ▶ It sets the variable next to the entry that should be next after lan.
  - ▶ How does it set next? (Easy!!)



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?
- ▶ SortedDLLPD addOrChangeEntry uses the output of find.
  - ▶ It sets the variable next to the entry that should be next after lan.
  - ▶ How does it set next? (Easy!!)
  - ▶ It sets the variable previous to the entry that should be before lan.





## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?
- ▶ SortedDLLPD addOrChangeEntry uses the output of find.
  - ▶ It sets the variable next to the entry that should be next after lan.
  - ▶ How does it set next? (Easy!!)
  - ▶ It sets the variable previous to the entry that should be before lan.
  - ▶ How does it set previous? (A little harder.)



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?
- ▶ SortedDLLPD addOrChangeEntry uses the output of find.
  - ▶ It sets the variable next to the entry that should be next after lan.
  - ▶ How does it set next? (Easy!!)
  - ▶ It sets the variable previous to the entry that should be before lan.
  - ▶ How does it set previous? (A little harder.)
- ▶ To insert new entry lan between next and previous, addOrChangeEntry has to set four pointers.



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?
- ▶ SortedDLLPD addOrChangeEntry uses the output of find.
  - ▶ It sets the variable next to the entry that should be next after lan.
  - ▶ How does it set next? (Easy!!)
  - ▶ It sets the variable previous to the entry that should be before lan.
  - ▶ How does it set previous? (A little harder.)
- ▶ To insert new entry lan between next and previous, addOrChangeEntry has to set four pointers.
  - ▶ What are they?



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?
- ▶ SortedDLLPD addOrChangeEntry uses the output of find.
  - ▶ It sets the variable next to the entry that should be next after lan.
  - ▶ How does it set next? (Easy!!)
  - ▶ It sets the variable previous to the entry that should be before lan.
  - ▶ How does it set previous? (A little harder.)
- ▶ To insert new entry lan between next and previous, addOrChangeEntry has to set four pointers.
  - ▶ What are they?
  - ▶ What method do we use?



## SortedDLLPD find and addOrChangeEntry

- ▶ SortedDLLPD find must tell us where to put lan if he is not there.
  - ▶ In that case it returns the entry after lan.
  - ▶ How does it know it has reached this entry?
  - ▶ What does it return if we were adding Zora?
- ▶ SortedDLLPD addOrChangeEntry uses the output of find.
  - ▶ It sets the variable next to the entry that should be next after lan.
  - ▶ How does it set next? (Easy!!)
  - ▶ It sets the variable previous to the entry that should be before lan.
  - ▶ How does it set previous? (A little harder.)
- ▶ To insert new entry lan between next and previous, addOrChangeEntry has to set four pointers.
  - ▶ What are they?
  - ▶ What method do we use?
  - ▶ For each of the four times, how do we call it and what is the value?



Keep it simple



# Keep it simple

- ▶ Keep each line of your program simple



# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.





# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:



# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:
  - ▶ `entry = head;`



# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:
  - ▶ `entry = head;`
  - ▶ `previous = next.getPrevious();`



# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:
  - ▶ `entry = head;`
  - ▶ `previous = next.getPrevious();`
  - ▶ `entry.setNext(next);`



# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:
  - ▶ `entry = head;`
  - ▶ `previous = next.getPrevious();`
  - ▶ `entry.setNext(next);`
  - ▶ `if (next == null)`



# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:
  - ▶ `entry = head;`
  - ▶ `previous = next.getPrevious();`
  - ▶ `entry.setNext(next);`
  - ▶ `if (next == null)`
- ▶ Of course you will use `getNext`, `setPrevious`, and other variable names!



# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:
  - ▶ `entry = head;`
  - ▶ `previous = next.getPrevious();`
  - ▶ `entry.setNext(next);`
  - ▶ `if (next == null)`
- ▶ Of course you will use `getNext`, `setPrevious`, and other variable names!
- ▶ And the three parts of a for-loop control should each be considered a “line”:



# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:
  - ▶ `entry = head;`
  - ▶ `previous = next.getPrevious();`
  - ▶ `entry.setNext(next);`
  - ▶ `if (next == null)`
- ▶ Of course you will use `getNext`, `setPrevious`, and other variable names!
- ▶ And the three parts of a for-loop control should each be considered a “line”:
  - ▶ `for (line1; line2; line3) {`





# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:
  - ▶ `entry = head;`
  - ▶ `previous = next.getPrevious();`
  - ▶ `entry.setNext(next);`
  - ▶ `if (next == null)`
- ▶ Of course you will use `getNext`, `setPrevious`, and other variable names!
- ▶ And the three parts of a for-loop control should each be considered a “line”:
  - ▶ `for (line1; line2; line3) {`
- ▶ Draw the diagram of what should happen.



# Keep it simple

- ▶ Keep each line of your program simple
- ▶ It should involve at most two variables.
- ▶ For example:
  - ▶ `entry = head;`
  - ▶ `previous = next.getPrevious();`
  - ▶ `entry.setNext(next);`
  - ▶ `if (next == null)`
- ▶ Of course you will use `getNext`, `setPrevious`, and other variable names!
- ▶ And the three parts of a for-loop control should each be considered a “line”:
  - ▶ `for (line1; line2; line3) {`
- ▶ Draw the diagram of what should happen.
- ▶ Write the line that makes that change happen.



speed



speed

- ▶ For DLLBasedPD (unsorted):



- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$



- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-)

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-)
  - ▶ binary search doesn't help

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-(
    - ▶ binary search doesn't help
    - ▶ because it takes  $O(n)$  to get to the middle element!

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-(
    - ▶ binary search doesn't help
    - ▶ because it takes  $O(n)$  to get to the middle element!
  - ▶ removal is now  $O(1)$ !

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-(
    - ▶ binary search doesn't help
    - ▶ because it takes  $O(n)$  to get to the middle element!
  - ▶ removal is now  $O(1)$ !
  - ▶ but removeEntry must call find

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-(
    - ▶ binary search doesn't help
    - ▶ because it takes  $O(n)$  to get to the middle element!
  - ▶ removal is now  $O(1)$ !
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$



- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-(
    - ▶ binary search doesn't help
    - ▶ because it takes  $O(n)$  to get to the middle element!
  - ▶ removal is now  $O(1)$ !
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ addition of an element is now  $O(1)$

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-(
    - ▶ binary search doesn't help
    - ▶ because it takes  $O(n)$  to get to the middle element!
  - ▶ removal is now  $O(1)$ !
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ addition of an element is now  $O(1)$
  - ▶ but addOrChangeEntry must call find

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-(
    - ▶ binary search doesn't help
    - ▶ because it takes  $O(n)$  to get to the middle element!
  - ▶ removal is now  $O(1)$ !
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ addition of an element is now  $O(1)$
  - ▶ but addOrChangeEntry must call find
  - ▶ so it is still  $O(n)$ .

- ▶ For DLLBasedPD (unsorted):
  - ▶ find is still  $O(n)$
  - ▶ removal is still  $O(1)$ , but for a different reason
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ Similarly, addOrChangeEntry is still  $O(n)$
- ▶ For SortedDLLPD (sorted):
  - ▶ find is now  $O(n)$  :-(
    - ▶ binary search doesn't help
    - ▶ because it takes  $O(n)$  to get to the middle element!
  - ▶ removal is now  $O(1)$ !
  - ▶ but removeEntry must call find
  - ▶ so it is still  $O(n)$
  - ▶ addition of an element is now  $O(1)$
  - ▶ but addOrChangeEntry must call find
  - ▶ so it is still  $O(n)$ .
- ▶ One step forward, two steps back!

# Summary



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,
  - ▶ in contrast to  $O(n)$  for an array.





# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,
  - ▶ in contrast to  $O(n)$  for an array.
  - ▶ But getting to the  $i$ th element takes  $O(n)$ ,



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,
  - ▶ in contrast to  $O(n)$  for an array.
  - ▶ But getting to the  $i$ th element takes  $O(n)$ ,
  - ▶ in contrast to  $O(1)$  for an array.



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,
  - ▶ in contrast to  $O(n)$  for an array.
  - ▶ But getting to the  $i$ th element takes  $O(n)$ ,
  - ▶ in contrast to  $O(1)$  for an array.
  - ▶ We will have to keep working on improving the running time.



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,
  - ▶ in contrast to  $O(n)$  for an array.
  - ▶ But getting to the  $i$ th element takes  $O(n)$ ,
  - ▶ in contrast to  $O(1)$  for an array.
  - ▶ We will have to keep working on improving the running time.
- ▶ When programming a linked list:



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,
  - ▶ in contrast to  $O(n)$  for an array.
  - ▶ But getting to the  $i$ th element takes  $O(n)$ ,
  - ▶ in contrast to  $O(1)$  for an array.
  - ▶ We will have to keep working on improving the running time.
- ▶ When programming a linked list:
  - ▶ Draw the diagram of each change.



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,
  - ▶ in contrast to  $O(n)$  for an array.
  - ▶ But getting to the  $i$ th element takes  $O(n)$ ,
  - ▶ in contrast to  $O(1)$  for an array.
  - ▶ We will have to keep working on improving the running time.
- ▶ When programming a linked list:
  - ▶ Draw the diagram of each change.
  - ▶ Program each change as a line



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,
  - ▶ in contrast to  $O(n)$  for an array.
  - ▶ But getting to the  $i$ th element takes  $O(n)$ ,
  - ▶ in contrast to  $O(1)$  for an array.
  - ▶ We will have to keep working on improving the running time.
- ▶ When programming a linked list:
  - ▶ Draw the diagram of each change.
  - ▶ Program each change as a line
  - ▶ with only two variables.



# Summary

- ▶ The *(doubly) linked list* is a new way to store a list.
  - ▶ Adding or removing an entry *at a known location* is  $O(1)$ ,
  - ▶ in contrast to  $O(n)$  for an array.
  - ▶ But getting to the  $i$ th element takes  $O(n)$ ,
  - ▶ in contrast to  $O(1)$  for an array.
  - ▶ We will have to keep working on improving the running time.
- ▶ When programming a linked list:
  - ▶ Draw the diagram of each change.
  - ▶ Program each change as a line
  - ▶ with only two variables.
  - ▶ Keep each step simple!

