CSE 12:
Basic data structures and object-oriented design

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Lecture Six
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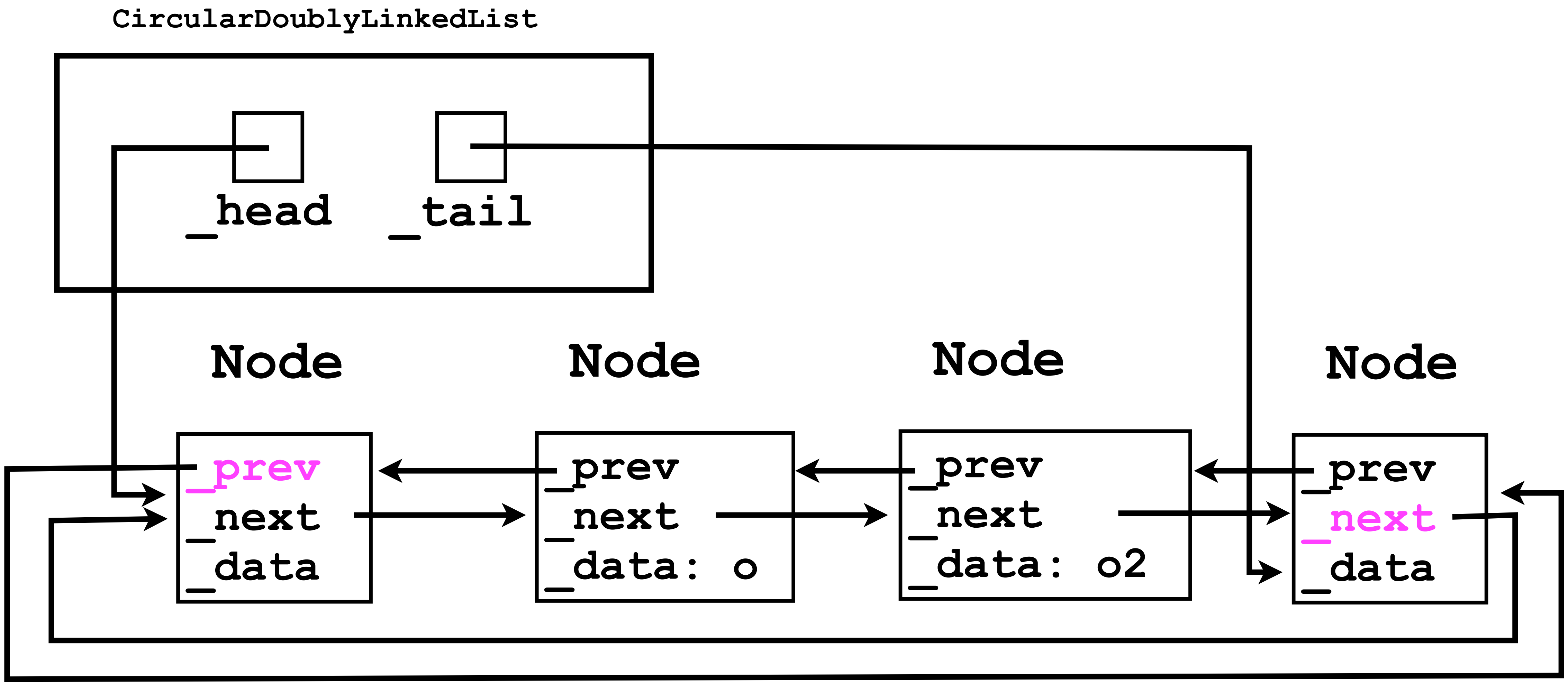
Circular linked lists.

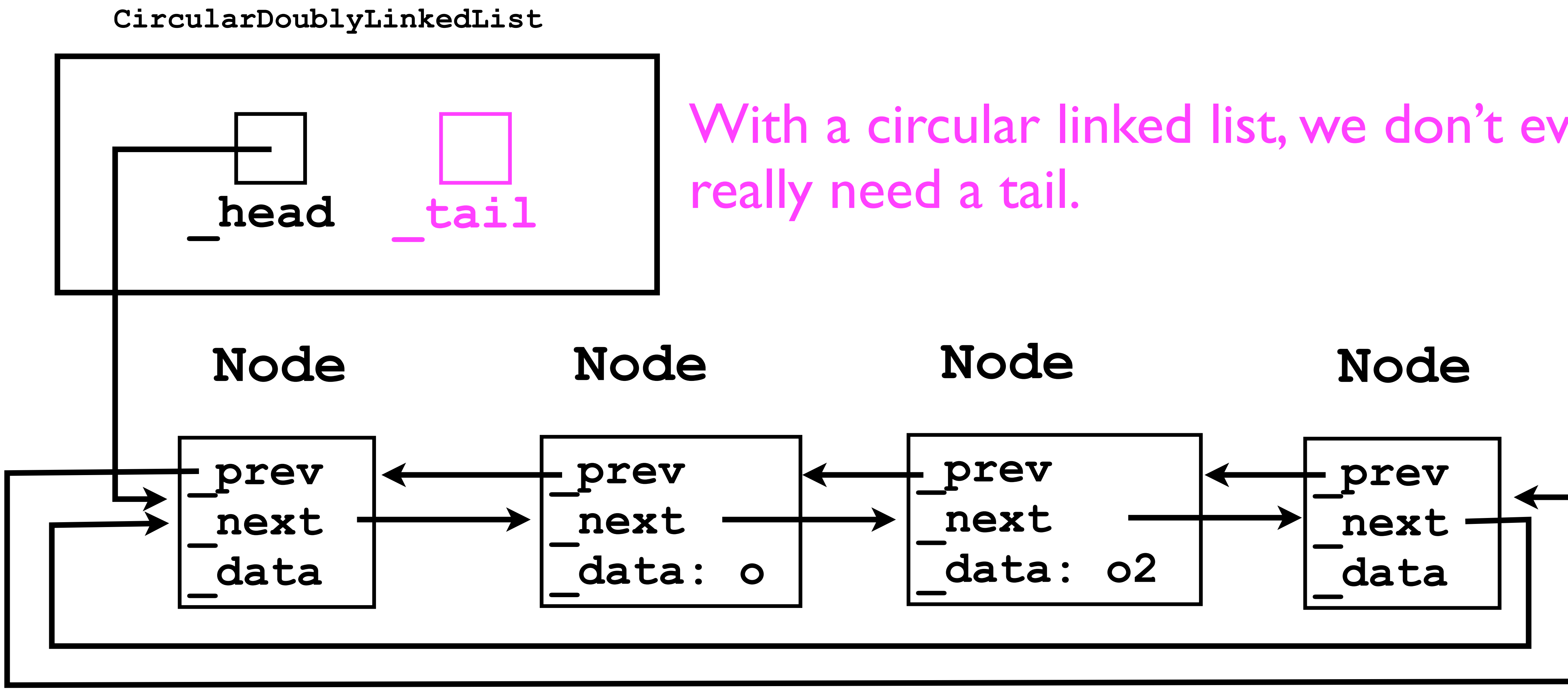
Circular linked lists

- Before moving on to other data structures, we will discuss one more variant of the basic "linked list" concept.
- A *circular linked list* is a list where the tail's "next" pointer points back to the *head*.
    - If the linked list is doubly-linked, then the head's "previous" pointer also points back to the *tail*.

Circular linked lists



Circular linked lists

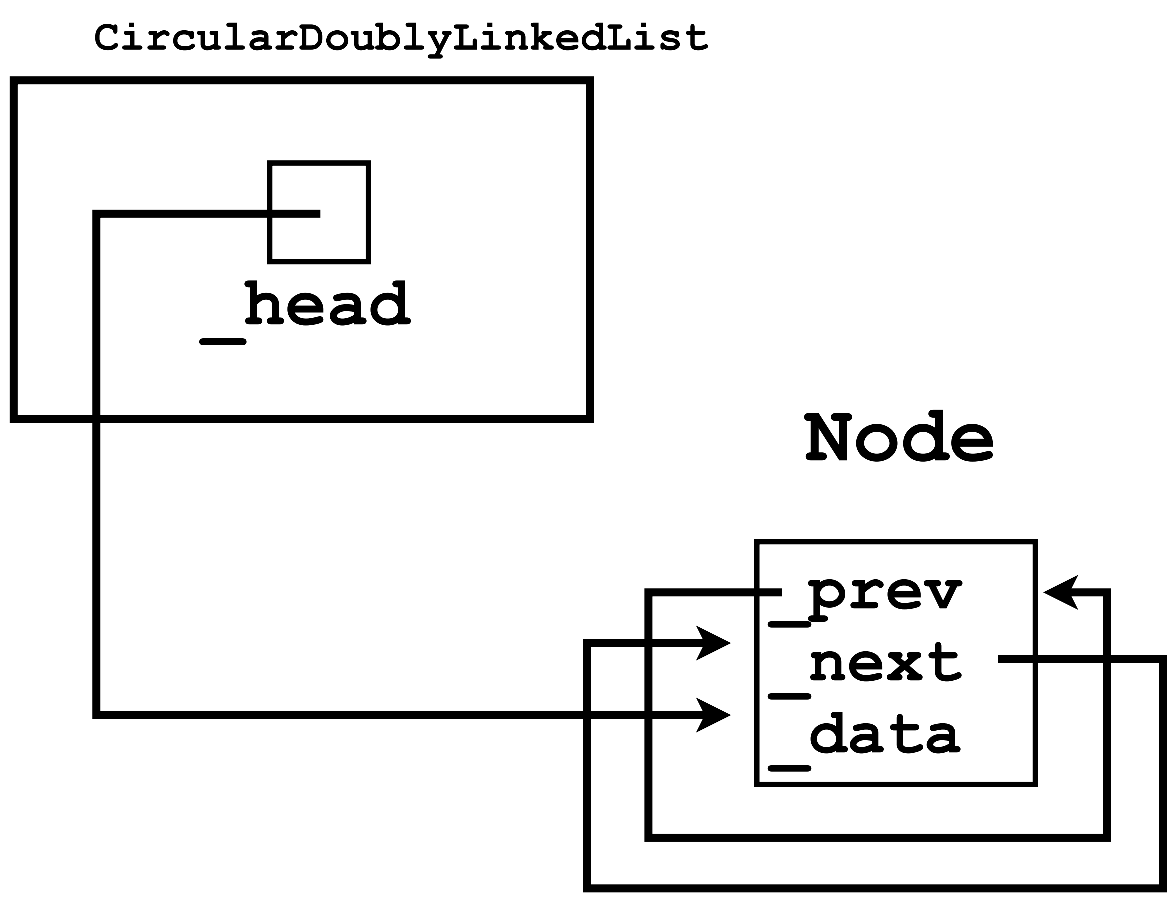


With a circular linked list, we don't even really need a tail.

Instead, all we really care about is whether we add to the front of the list (to the "right" of _head), or to the back of the list (to the "left" of _head).

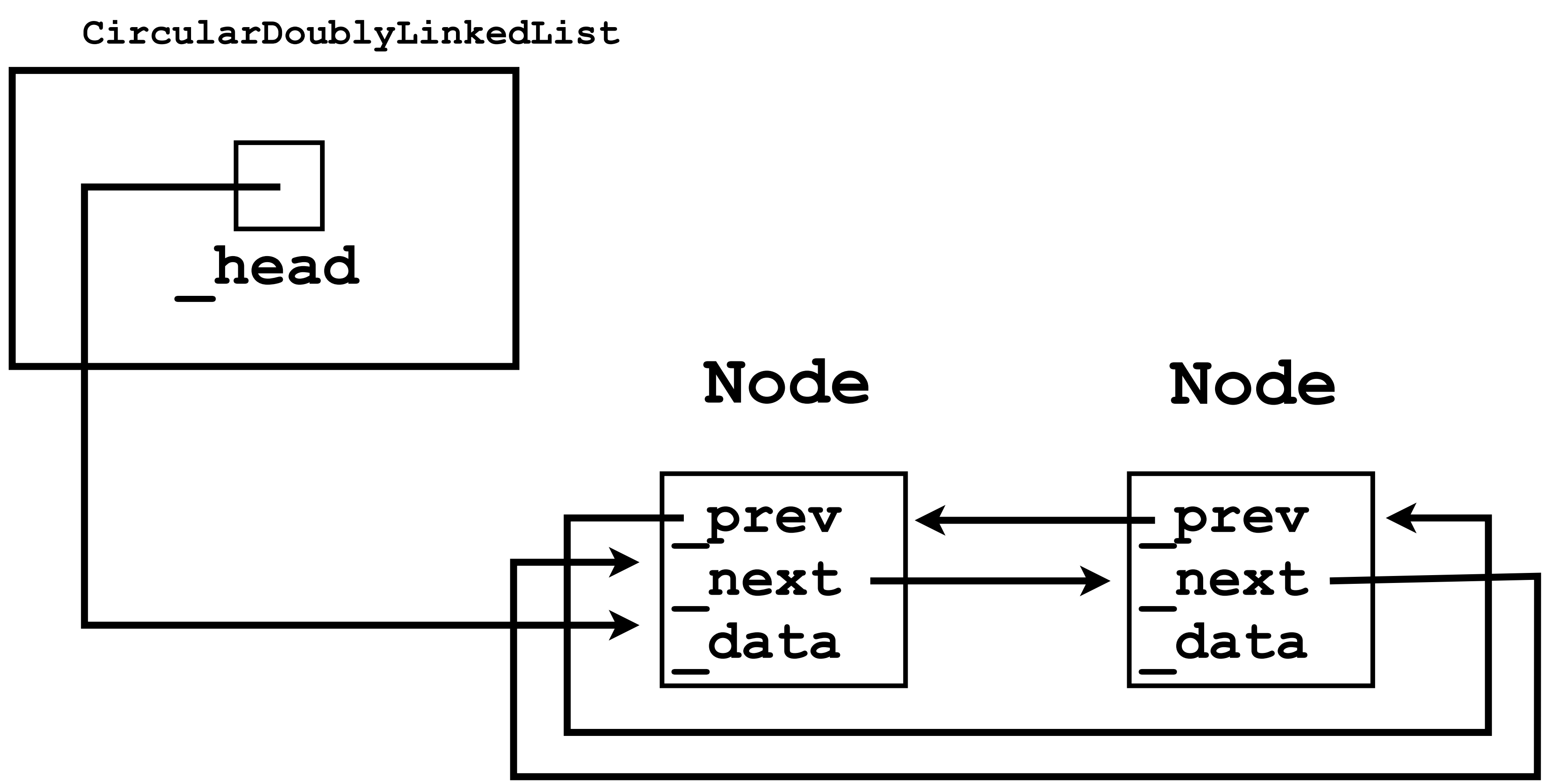
Circular linked lists

- The utility of circular linked lists is perhaps most clearly illustrated when there are no dummy nodes.
- Empty list: `_head = null`.
- List of size 1:



Circular linked lists

- List of size 2:



Iterating through a circular linked list

- As long as a circular linked list is non-empty, an `Iterator` can iterate *forever*.
  - Just keep following the current `Node`'s `_next` pointer.

```
class CircularListIterator {
  Node _current;
  ...
  boolean hasNext () {
    return _listSize > 0;
  }
  Object next () {
    _current = _current._next;
    return _current._data;
  }
}
```

Simulating a circular linked list

- Using `DoublyLinkedList12` (with dummy nodes, but without pointers to "loop back around"), we can easily simulate a circular linked list.

- In `Iterator.next()`, if we've iterated to the tail, then just start back over at the head...

```
Object next () {
  if (_current == _tail) {  // Loop back
    _current = _head;
  }
  _current = _current._next;
  ...
}
```

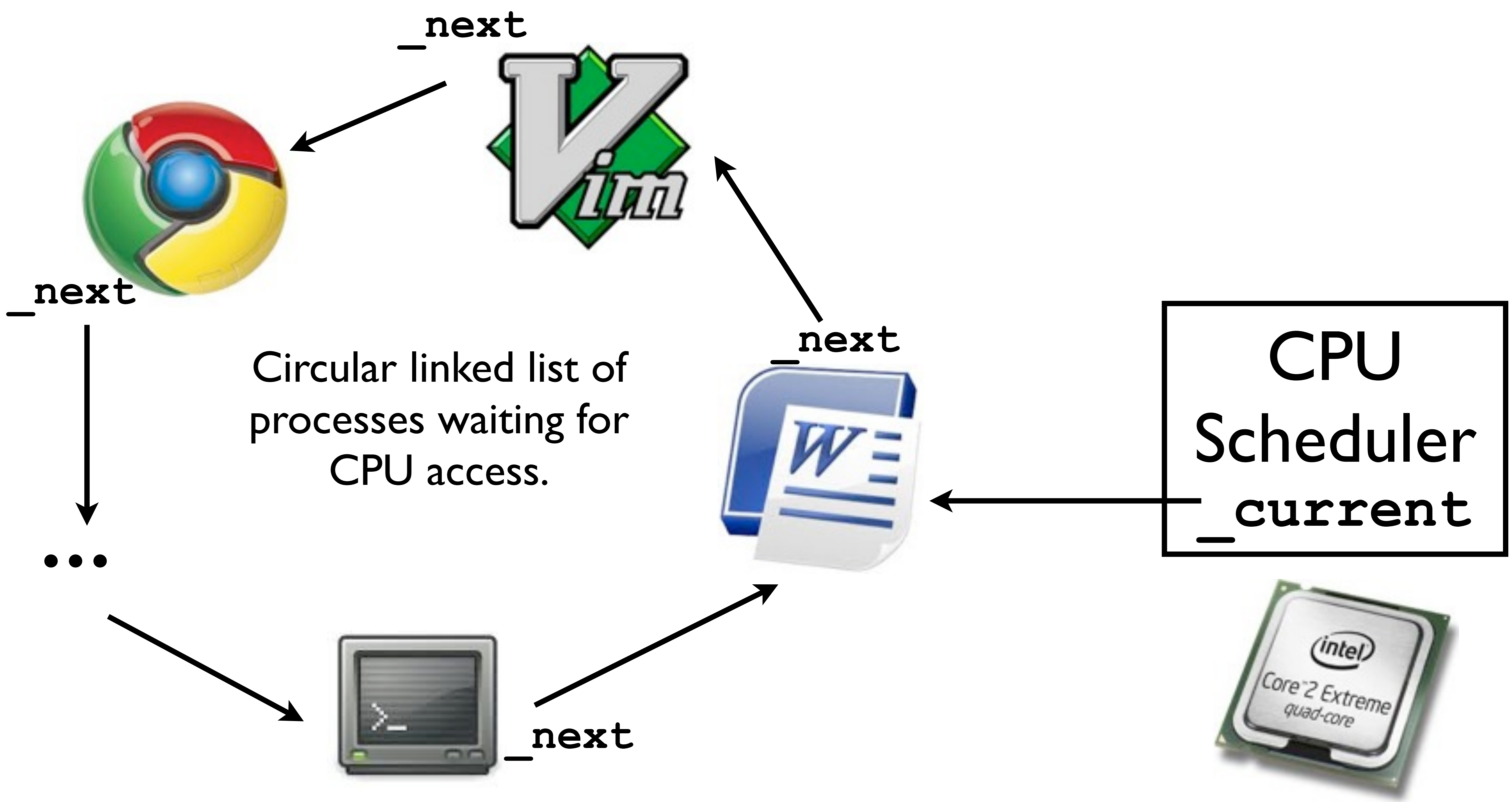
Circular linked lists

- Circular linked lists are most useful for storing a collection of objects in which "looping forever" is an intuitive and useful operation.
- Examples:
  - Looping around vertices of a polygon.

Circular linked lists

- CPU scheduling:
  - One CPU can only execute one computer program at any given time.
  - On a single-core machine, to simulate "multitasking", each program is given a small "timeslice" (few milliseconds) to run on the CPU.
  - After the timeslice expires, the *next* program in the list of processes is selected, and so on.
  - After all programs in the list have received their timeslice, the CPU scheduler goes back to the first process.

Circular linked lists for CPU scheduling



Type-safety and casting.

Type-safety in Java

- As mentioned in Lecture Three, Java was designed from the ground up to offer *security*.
- One aspect of security is ensuring that a variable that, for example, is supposed to point to a String doesn't actually point to an Integer.

```
// Won't compile
final String s = new Integer(6);
```

- This form of security is known as *type-safety*.

Type-safety in Java

- That example was somewhat obvious; let's look at a more subtle one...

```
final Object o = new Integer();
final String s = (String) o;
```

This code will compile ok, ...

Type-safety in Java

- That example was somewhat obvious; let's look at a more subtle one...

```
final Object o = new Integer();
final String s = (String) o;  // Compiles ok
```

...but at run-time, the second statement will trigger a **`ClassCastException`** -- an **`Integer`** is never also a **`String`**!

Type-safety

- Java and the JVM enforce type-safety:
  - Every `Object` knows what kind of class it is, what its parent class is, and all the interfaces that it implements.
  - If you attempt to "cast" an object into a type with which it is not compatible, then this will trigger a `ClassCastException`.
    - Your program will terminate.

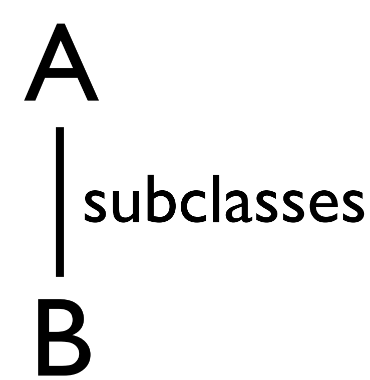
Casting

- In object-oriented languages like Java, objects are *cast* into different classes/interfaces when we assign them to reference variables of *different types*.

- Consider:

```
class A { ...
}
class B extends A { ...
}

B b = new B();
A a = b;         // Upcast from B to A.
B b2 = (B) a;    // Downcast from A to B.
```



The terms upcast and downcast have to do with the class hierarchy, in which parent classes are “above” child classes.

Upcasting

- If class `B` is a subclass of `A`, and we convert a reference of type `B` to a reference of type `A`, then we are upcasting, e.g.: `A a = b;`
  - Since all objects of type `B` are implicitly also of type `A`, this cast is *guaranteed to succeed*.
  - Every object of type `B` can also be treated as an object of type `A`.
    - All methods and instance variables of `A` are guaranteed to be accessible.

Downcasting

- If class `B` is a subclass of `A`, and we convert a reference of type `A` to a reference of type `B`, then we are downcasting, e.g.: `B b = (B) a;`
  - Since objects of type `A` are *not guaranteed* to always also be of type `B`, we must explicitly inform the compiler that we "know" that `b` is of class `B`.
    - We must explicitly "request" the cast by writing `(B)`.

Downcasting

- At run-time, before performing the cast from class **`A`** to **`B`**, the JVM will check whether **`b`** is actually a **`B`** object.
  - If it is, then execution proceeds merrily.
  - If not, then the JVM will throw a **`ClassCastException`**.

Casting to interfaces

- We can also cast to an interface type, e.g.:

```
Object o = new DoublyLinkedList12();
Iterable iterable = (Iterable) o;
```

- Since not every object of **`Object`** class is guaranteed to implement the **`Iterable`** interface, we must "downcast" to **`Iterable`**.
- At run-time, the JVM will check whether **`o`** is of some class that implements **`Iterable`**, and throw a **`ClassCastException`** if it is not.

Importance of type-safety

- Not all languages are type-safe.
- In C++, for example, the compiler is happy to compile the following code:

Here, we "force" the compiler to treat the `Integer` pointer as a `Student` pointer.

```
Integer *integer = new Integer(123);
Student *student = (Student *) integer;
student->_age = 23;
```

Here we attempt to modify the `_age` instance variable of a "`Student`" object. But `student` actually points to an `Integer` object!

Danger in casting

- The outcome of this program can't be good -- we're trying to modify the "`_age`" of an `Integer` object!
- What's going on here in terms of memory?
- Let's first convert this example to Java...

Danger in casting

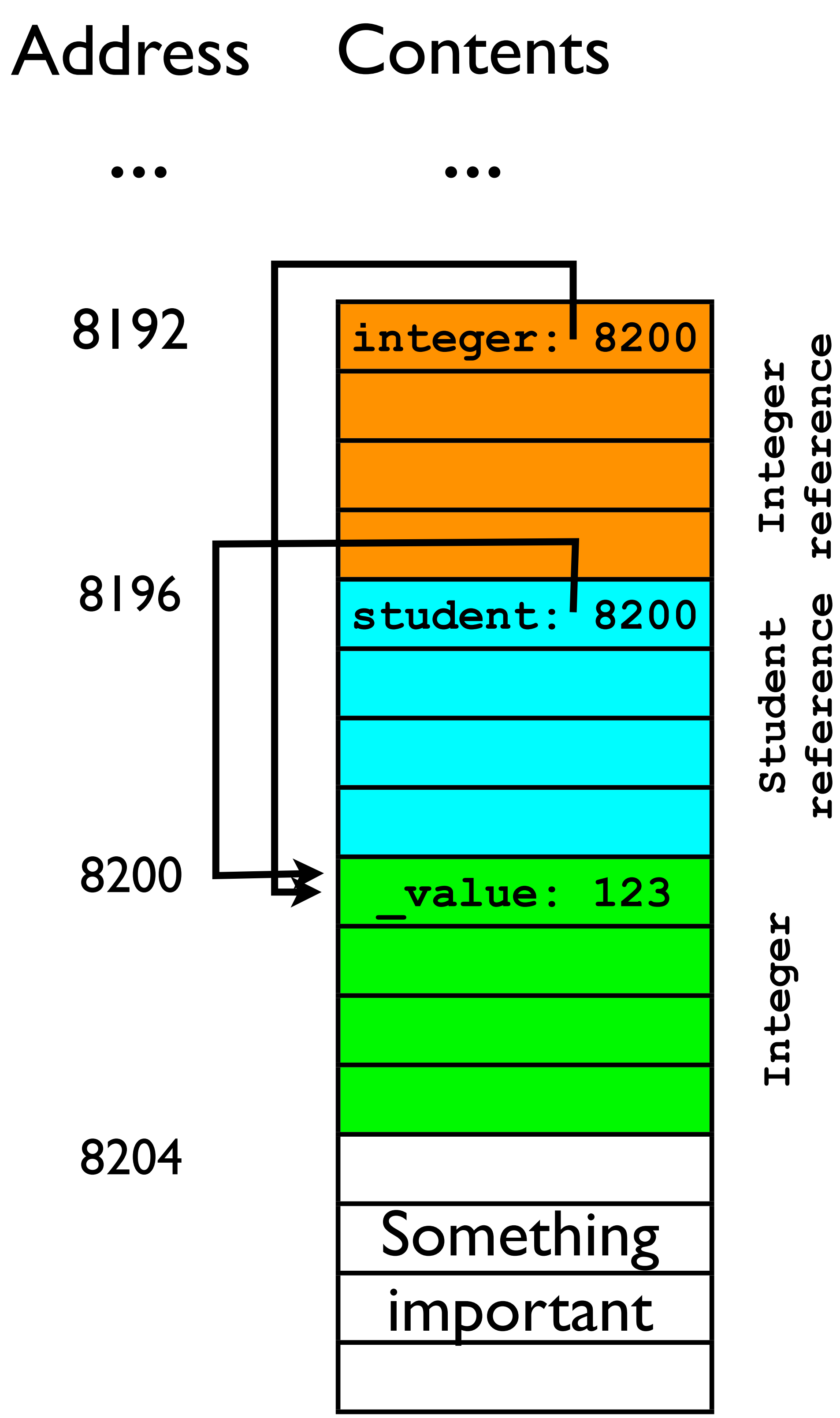
- Let's assume the following class definitions:

```
class Integer {  // 4 bytes total
  int _value;
}

class Student {  // 8 bytes total
  String _name;
  int _age;
}
```

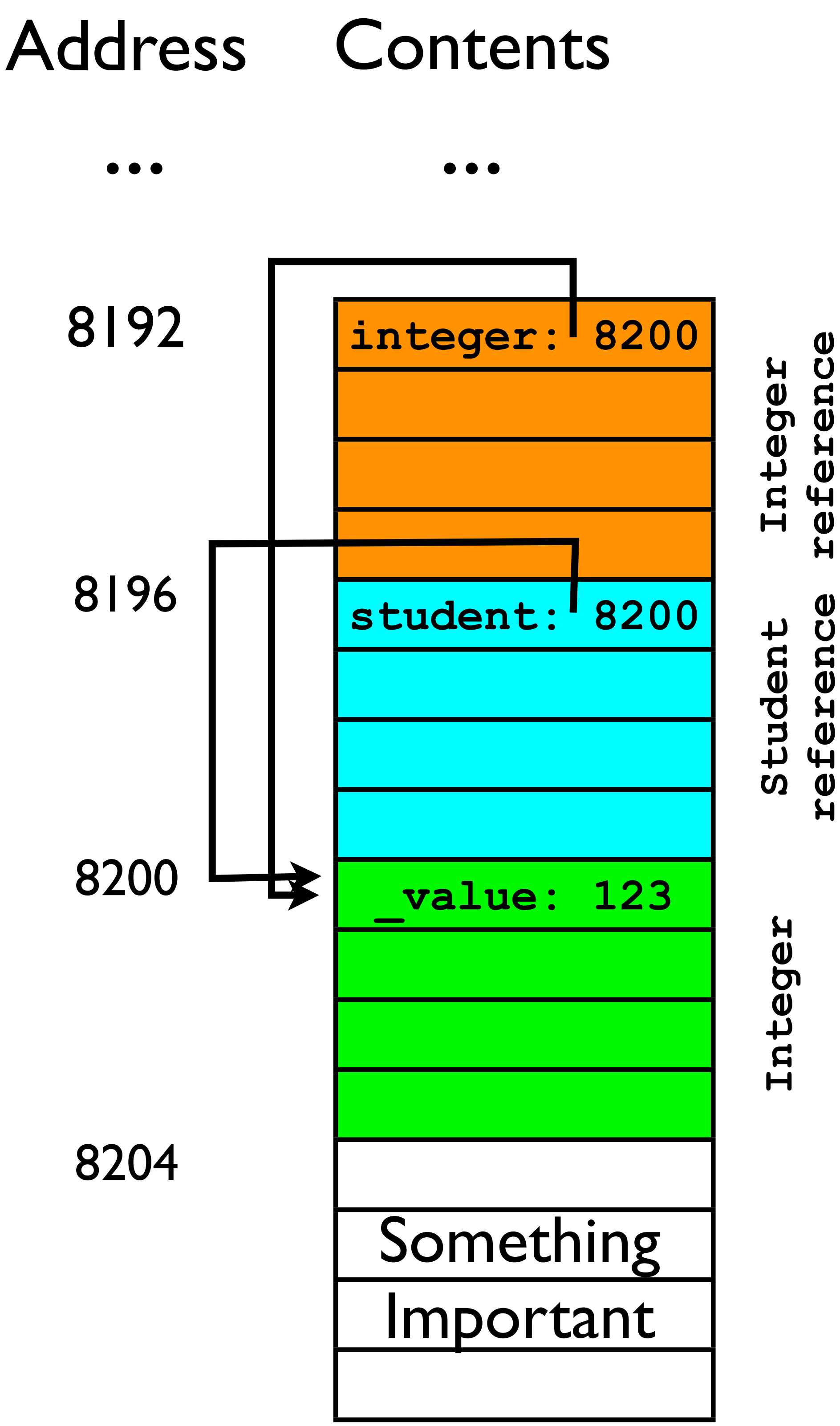
Danger in casting

```
Integer integer = new Integer(123);
Student student = (Student) integer;
```

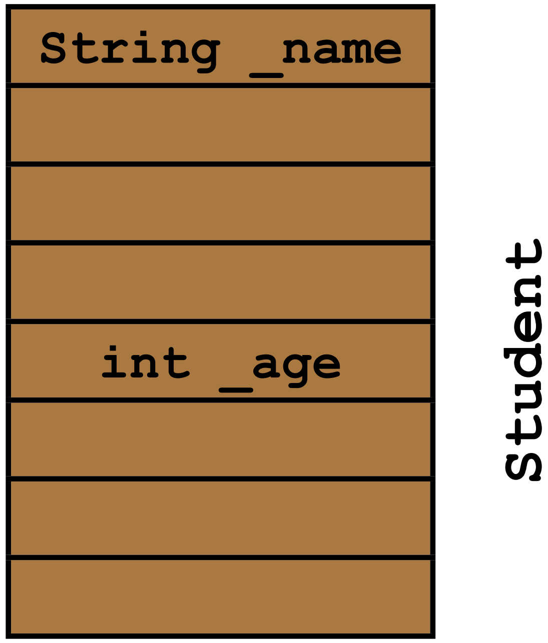


Danger in casting

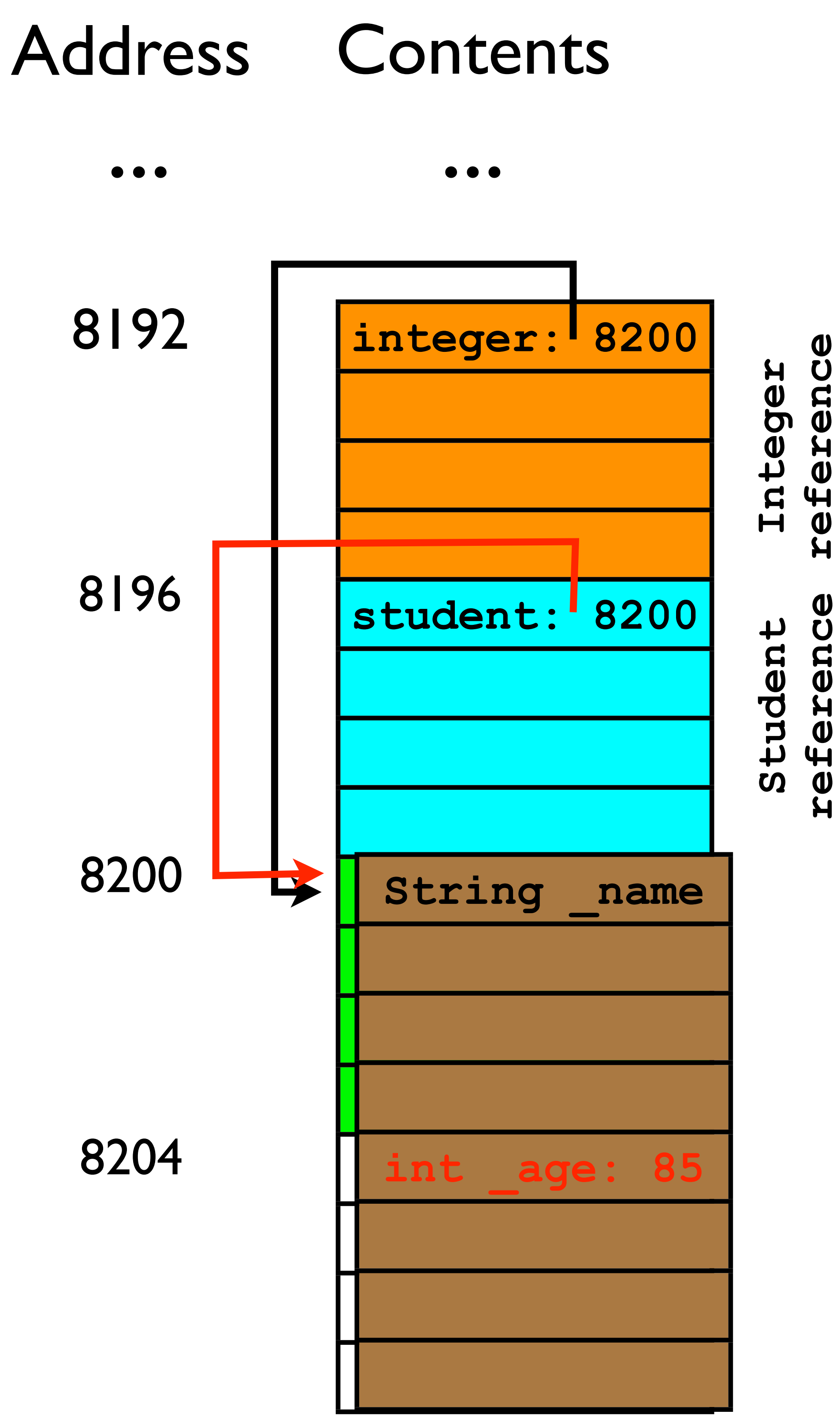
```
Integer integer = new Integer(123);
Student student = (Student) integer;
```



Let's also suppose a "real" `Student` object would look like this:



Danger in casting




```
Integer integer = new Integer(123);
Student student = (Student) integer;
student._age = 85;
```

- In the last line of code, the program attempts to modify the "`_age`" instance variable of the "`Student`" object pointed to by `student`.
    - `_age` *would be* stored at 8204.
- In reality, `student` actually points to an `Integer` object.
    - That `Integer` object does not own address 8204!
    - Something Important has been clobbered.

Clobbering memory

- When you write data outside of a variable's "proper bounds", you are "clobbering memory".
- In the previous example, treating the **`Integer`** like a **`Student`** caused the statement **`student._age = 85`** to overwrite Something Important.
- Without Java's protective type safety, this could cause your program to:
  - Crash.
  - Behave in unexpected ways at some indeterminate point in the future. <== Often worse than crashing.

Clobbering memory

- In some settings (e.g., a web server application that processes data sent from user), treating a variable as an object of the wrong type could be exploited by an attacker.
  - By causing your code to "clobber" the right memory, an attacker might gain control of your entire machine. :-(

Type-safety in Java

- Java and the JVM help to prevent such attacks.
- All downcasts are checked by the JVM to make sure they are valid before execution proceeds.
- As always, this added security comes at a cost:
    - A downcast in Java is slower than a downcast in C++.

Java collections before generics.

Java Collections Framework

- Since Java version 1.2, the JDK has offered pre-built "collections" of various types as part of the Java Collections Framework (JCF).
- The JCF includes such classes as:
  - **`ArrayList`**
  - **`Vector`**
  - **`HashTree`**
  - **`Set`**
  - etc., etc.

CSE12 Collections

- In this course, we have worked on two "collections" -- `ArrayList`, and `DoublyLinkedList12`.
- Similar to the JCF collections in Java 1.2, our collections have dealt with Objects:
  - `public void add (Object o);`
  - `public Object get (int index);`
- Every object in Java is of type `Object`; hence, these collections can store variables of *any type*.

Collections of Objects

- Hence, the same class **`ArrayList`** can be used to create a list of **`String`**s as well as a list of **`Integer`**s:

```
final ArrayList listOfStrings = new ArrayList();
listOfStrings.add("yo");

final ArrayList listOfIntegers = new ArrayList();
listOfIntegers.add(new Integer(32));
```

- This is convenient -- we don't have to create a two different classes to store **`String`**s versus **`Integer`**s.

Downside of downcasting

- Unfortunately, the fact that the `List12` interface takes and returns `Objects` also means that we have to *downcast* the `Object` every time we call `get(index)`:

```
list.add("hello");
final String s = (String) listOfStrings.get(0);
```

- Having to downcast every time is both *tedious* and *distracting* because it litters the code with parentheses and class names.

Downside of downcasting

- There's also a security reason why downcasting an `Object` returned by a collection is bad:
  - We may accidentally try to downcast an `Object` to an incompatible type.

Downside of downcasting

- Consider a method in which you use several collections to store data of several types:

```
ArrayList list1, list2, list3;
list1 = new ArrayList();  // for Strings
list2 = new ArrayList();  // for Integers
list3 = new ArrayList();  // for Students
list1.add("test");
list2.add(new Integer(17));
list2.add(new Integer(42));
...
list3.add(new Student());
list1.add(new Student());
list2.add(new Integer(4));
list1.add("another string");
```

Downside of downcasting

- Consider a method in which you use several collections to store data of several types:

```
ArrayList list1, list2, list3;
list1 = new ArrayList();  // for Strings
list2 = new ArrayList();  // for Integers
list3 = new ArrayList();  // for Students
list1.add("test");
list2.add(new Integer(17));
list2.add(new Integer(42));
...
list3.add(new Student());
list1.add(new Student());  // Wrong list!
list2.add(new Integer(4));
list1.add("another string");
```

Downside of downcasting

- If we later retrieve an `Object` from `list1` and assume (incorrectly) that it contains only `String`s, our program will crash:

```
final Iterator iterator = list1.iterator();
while (iterator.hasNext()) {
  final String s = (String) iterator.next();
  ...
}
```

Given the code on previous slide, this will trigger a `ClassCastException`.

- It is still nice that the JVM catches our mistake at *run-time*, but it would be even *nicer* for the Java compiler to catch our mistake at *compile-time*.

Downside of downcasting

- Unfortunately, with collections of `Objects`, this is not really possible.
- The compiler has no way of "knowing" that `list1` was intended "only for `Strings`".
  - `ArrayList.add(o)` is happy to accept any `Object o`.

More plausible example

- A more plausible example of the problem above might occur if you are implementing a method that takes a collection as a *parameter*:

```
// Specified list should contain only Strings.
// Returns a list of appended strings.
List12 appendStrings (List12 strList) {
  List12 appendedStrList = new ArrayList();

  final Iterator iterator = strList.iterator();
  while (iterator.hasNext()) {
    appendedStrList.add(
      "appendage" + (String) list.next()
    );
  }
  return appendedStrList;
}
```

More plausible example

- A more plausible example of the problem above might occur if you are implementing a method that takes a collection as a *parameter*:

```
// Specified list should contain only Strings.
// Returns a list of appended strings.
List12 appendAndPrint (List12 strList) {
  List12 appendedStrList = new ArrayList();

  final Iterator iterator = list.iterator();
  while (iterator.hasNext()) {
    appendedStrList.add(
      "appendage" + (String) list.next()
    );
  }
  return appendedStrList;
}
```

If user passed in a list that contained any non-`String` object, then we'll get a `ClassCastException`.

Naive fix

- How can we fix the problems of tedium, ugly code, and potential **`ClassCastExceptions`**?
- One naive strategy is to define a different **`ArrayList`** for every class we want to store in it, e.g.:

With specific types, we no longer have to downcast the result, and we're guaranteed that `get(index)` returns a `String`.

```
class ArrayListOfStrings {
  public void add (String s) { ... }
  public String get (int index) { ... }
}
class ArrayListOfIntegers {
  public void add (Integer i) { ... }
  public Integer get (int index) { ... }
}
class ArrayListOfShapes {
  public void add (Shape s) { ... }
  public Shape get (int index) { ... }
}
```

Naive fix

- However, this "naive fix" is very tedious -- we have to create another version of the `ArrayList` for every class we want to support.
- "Copying+pasting code" would save some time, but this is never a good idea.
  - Inevitably, one of the `ArrayListOfX` classes will change, and you'll forget to change the other ones correspondingly.
- Let's take another look at those "related classes"...

Better fix: factor out the type

```
class ArrayListOfStrings {
  public void add (String s) { ... }
  public String get (int index) { ... }
}
class ArrayListOfIntegers {
  public void add (Integer i) { ... }
  public Integer get (int index) { ... }
}
class ArrayListOfShapes {
  public void add (Shape s) { ... }
  public Shape get (int index) { ... }
}
```

- The *only* place these class definitions differ is in the *type* of the objects they hold.
- It seems like there should be a way to "factor out" the type...

Java generics.

Java generics

- Since Java 1.5, Java has offered the ability to parameterize a class by a type.
  - For example, when writing a "collection" class such as **`ArrayList`**, we can give it a type parameter **`T`**.
    - As with data parameters, the parameter name is up to the programmer.
    - Type parameters are typically given one-letter names:
      - **`K`** for "key", **`V`** for "value", **`E`** for "element, etc.

Generics for "**`ArrayListOfX`**"

- Consider our problem of writing multiple **`ArrayListOfX`** classes to store data of different types:
  - With Java generics, we can write just one version of the class and parameterize it by type **`T`**, the type of data the **`ArrayList`** should contain.

Generics for "`ArrayListOfX`"

```
class ArrayList<T> implements List<T> {
  T[] _underlyingStorage;
  int _numElements;

  void add (T element) {
    _underlyingStorage[_numElements] = element;
    _numElements++;

  T get (int index) {
    return _underlyingStorage[index];
  }
}
```

Interfaces too can be parameterized by a type.

The type parameter **`T`** is specified in angled brackets just after the classname. Thereafter, it can be used inside the class anywhere a type is expected. (Almost -- more later.)

Generics for "`ListOfX`"

- Similarly to classes, interfaces too can be parameterized by a type:

```
interface List<T> {
  void add (T element);
  T get (int index);
  void remove (int index);
}
```

Generics for "**ArrayListOfX**"

- In short: (almost) everywhere in our previous versions of **List** and **ArrayList**, we replace the type **Object** with the type parameter **T**.

- To instantiate the "generic" **ArrayList<T>** in code:

  When we instantiate the generic collection, we must specify the *value* of the type parameter.

```
final ArrayList<Student> list = new ArrayList<Student>();
```

- Instantiating the **ArrayList** with type parameter **T=Student** can be *conceptualized* as doing a "search-and-replace" to change **<T>** to **<Student>**:

```
class ArrayList<T> ... {
  void add (T element) { ...
  }
  T get (int index) { ...
  }
}
```

→

```
class ArrayList ... {
  void add (Student element) { ...
  }
  Student get (int index) { ...
  }
}
```

Generics for "**ArrayListOfX**"

- Now, our list can *only* be populated with **Student** data (or any *subclass* of **Student**):

```
list.add(new Student());  // -- ok by definition
list.add(new UCSDStudent());  // -- ok if it's a subclass
```

- What happens if we try to break this rule and add a non-**Student** object to list?

```
list.add("error");  // not ok -- compiler catches this!
```

Generics for "ListOfX"

- Now, our list can *only* be populated with **`Student`** data (or any *subclass* of **`Student`**):

```
list.add(new Student());  // -- ok by definition
list.add(new UCSDStudent());  // -- ok if it's a subclass
```

- What happens if we try to break this rule and add a non-**`Student`** object to list?

```
list.add("error");  // not ok -- compiler catches this!
```

- With Java generics, the compiler will catch this error -- it knows that "error" is a **`String`**, and that list is of type **`ArrayList<Student>`**.
  - Since **`ArrayList<Student>`**'s add(element) method expects a **`Student`**, there is a type mismatch -- *compile-time* error.

Benefits of generics

- It is preferable for the compiler to catch this mistake rather than the JVM:
  - We fix the bug *before* the program crashes.
  - The compiler *rules out the possibility* that we mismatch container type and element type.
- With generics, we also no longer have to *downcast* the return value of **`get(index)`**:

```
final ArrayList<String> list = new ArrayList<String>();
list.add("hello");
final String s = list.get(0);  // No downcast necessary
```

  - This is because the result of **`get(index)`** is *guaranteed* to be of type **`String`** -- we don't have to additionally "promise" the compiler anything.