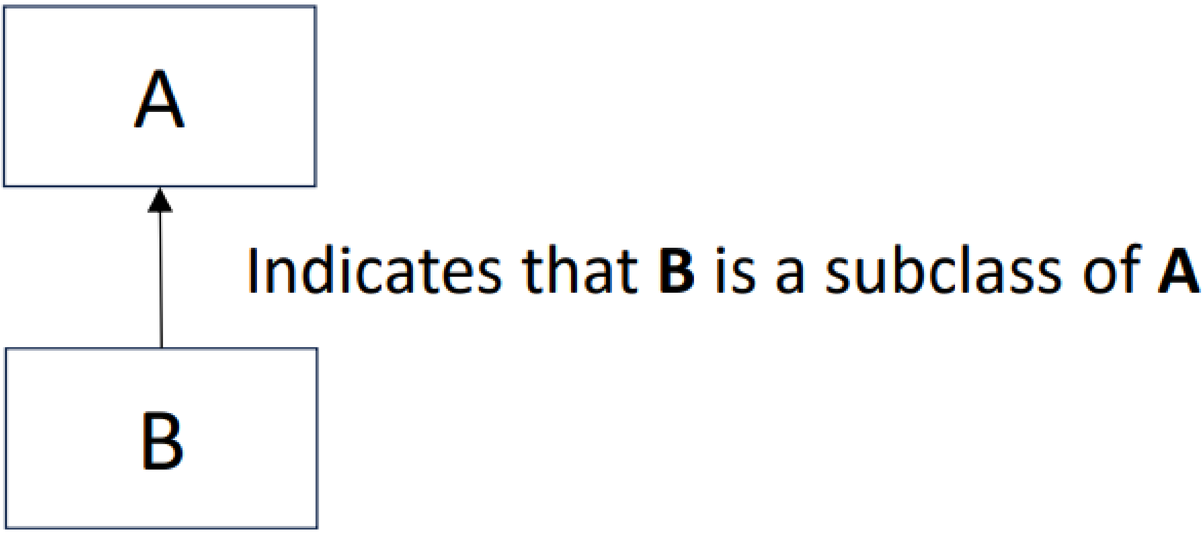
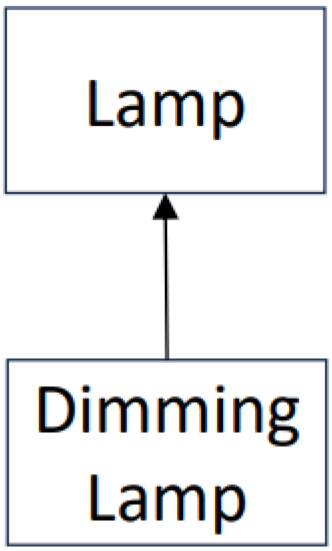
Inheritance and Abstract Classes – Part 2

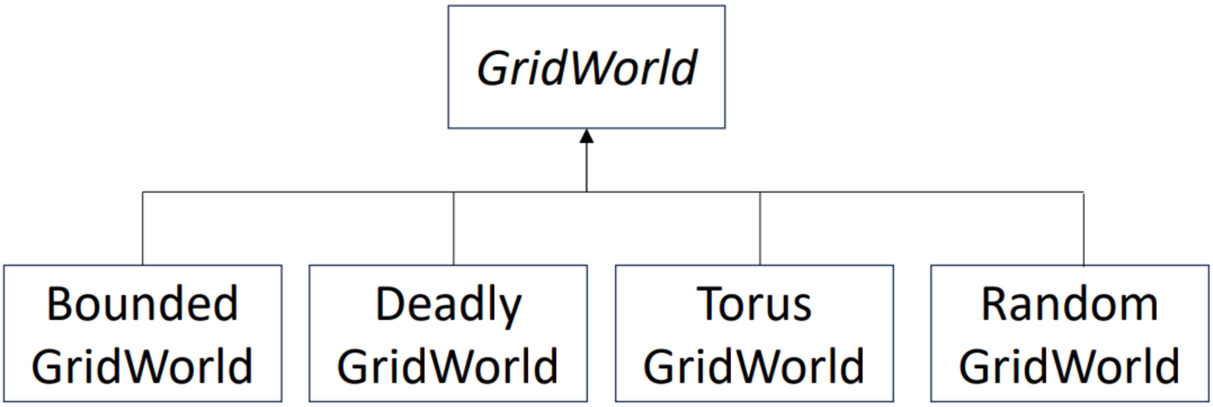
Class diagrams

Useful notation to sketch class relationships during design, or in documentation

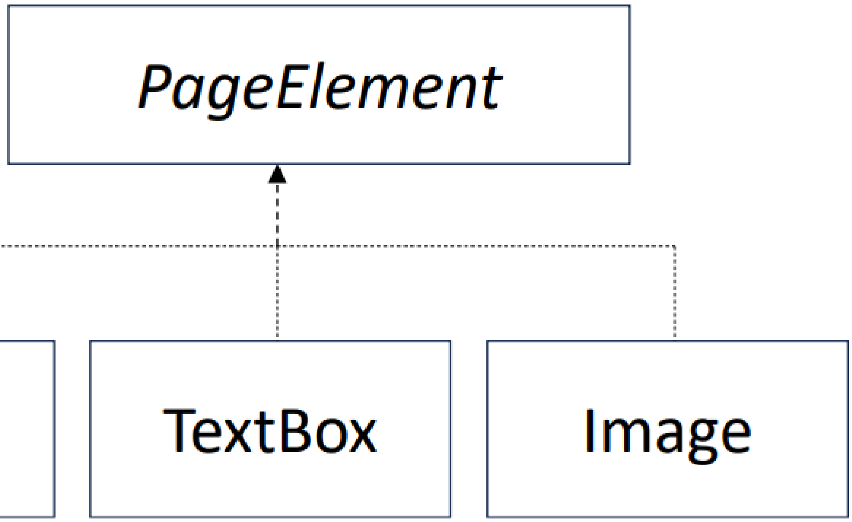




Sometimes *italics* are used for abstract class or interface



Sometimes dashed line used to indicate implementation of interface



Extending interfaces

- Interface B can extend an interface A by adding additional method signatures
- To implement B, a class must provide all the methods required by A, plus any additional methods required by B
- The existing interface A specifies a service
- The interface B that extends A specifies a larger service

`MutableIterator` extends `Iterator`

```
interface Iterator<T> {
    fun next(): T
    fun hasNext(): Boolean
}

interface MutableIterator<T> : Iterator<T> {
    fun remove()
}
```

A class implementing `MutableIterator` must provide the service that `Iterator` offers, plus the extra `remove` method

Subtyping

- Let T and U be class / interface types
- U is a subtype of T if U offers at least the service that T offers
- If U is a subtype of T then T is a supertype of U

Suppose that client code has been designed to work with an object of type T. The client depends on the service provided by T. Therefore, the client can work with an object of type U whenever U is a subtype of T.

Subtyping: `Lamp` and `DimmingLamp`

`Lamp` provides a simple service:

- `pressSwitch`
- `toString`

`DimmingLamp` provides this service, plus more (`up` , `down`)
The `DimmingLamp` subclass is therefore a subtype of `Lamp` – it provides at least the service that `Lamp` provides

Subtyping rules: reflexivity and transitivity

Reflexivity: for any type T, T is a subtype of T

Transitivity: for types T, U and V:

- if V is a subtype of U
- and U is a subtype of T
- then V is a subtype of T

Subtyping rules: upper and lower bounds

Let T be a class or interface

- T is a subtype of `Any?`
- `Nothing` is a subtype of T

`Nothing` is a type that has no values – it can be used as a return type to indicate that a method is guaranteed to throw an exception.

Throwing an exception is not the same as returning a value.

Subtyping rules: extending and implementing

Let T be a class or interface, and let U be a class or interface

- If U extends T then U is a subtype of T
- If U implements T then U is a subtype of T

In the “implements” case, U must be a class and T an interface

Subtyping rules: nullability

Let T be a class or interface

- T is a subtype of T?

A weird type: Nothing?

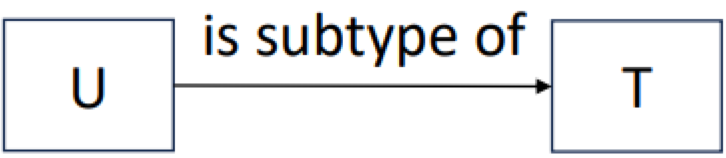
`Nothing` has no values, so `Nothing?` has one possible value: `null`

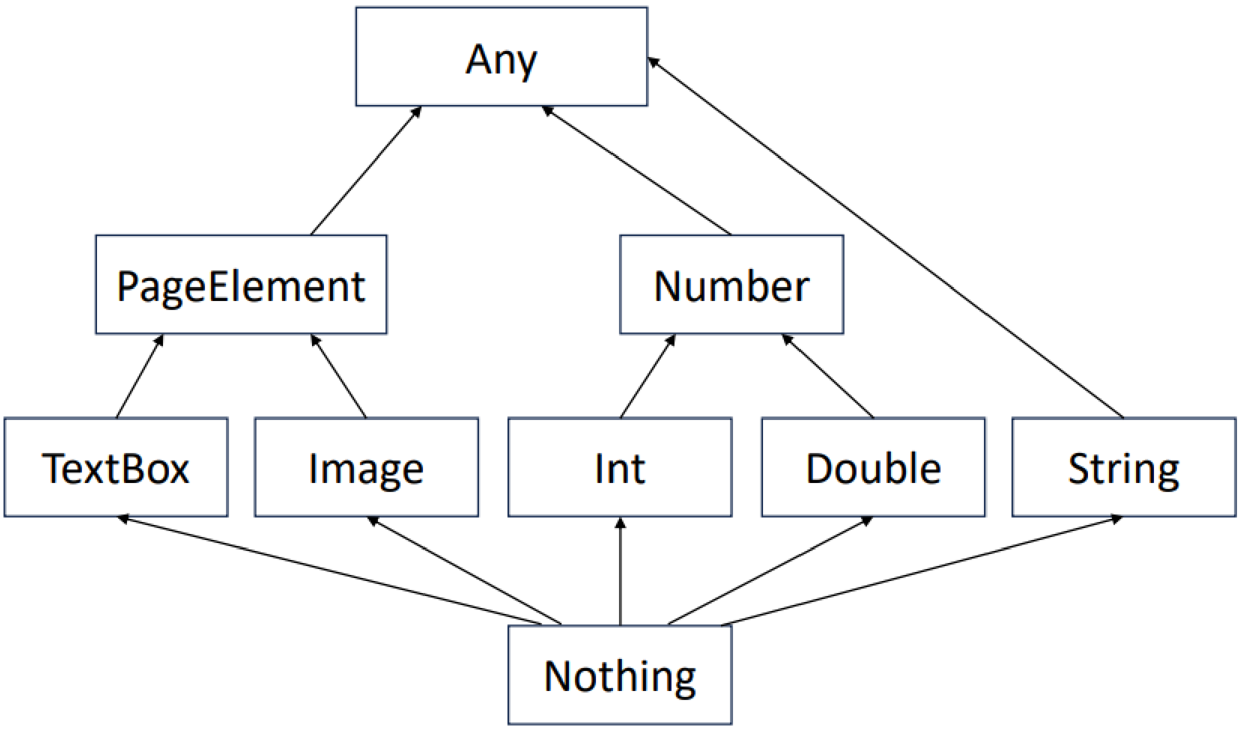
```
fun handleString(s: String) {
    …
}

fun main() {
    val x = null
    handleString(x)
}
```

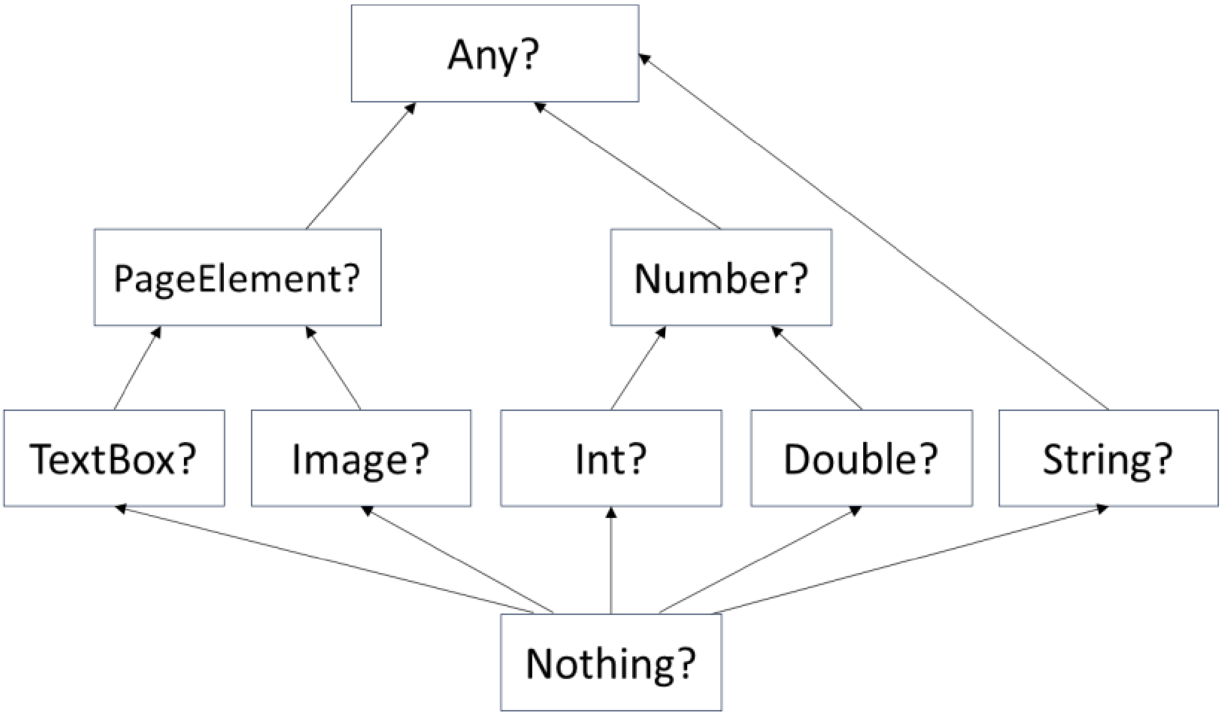
The inferred type for `x` is `Nothing?`

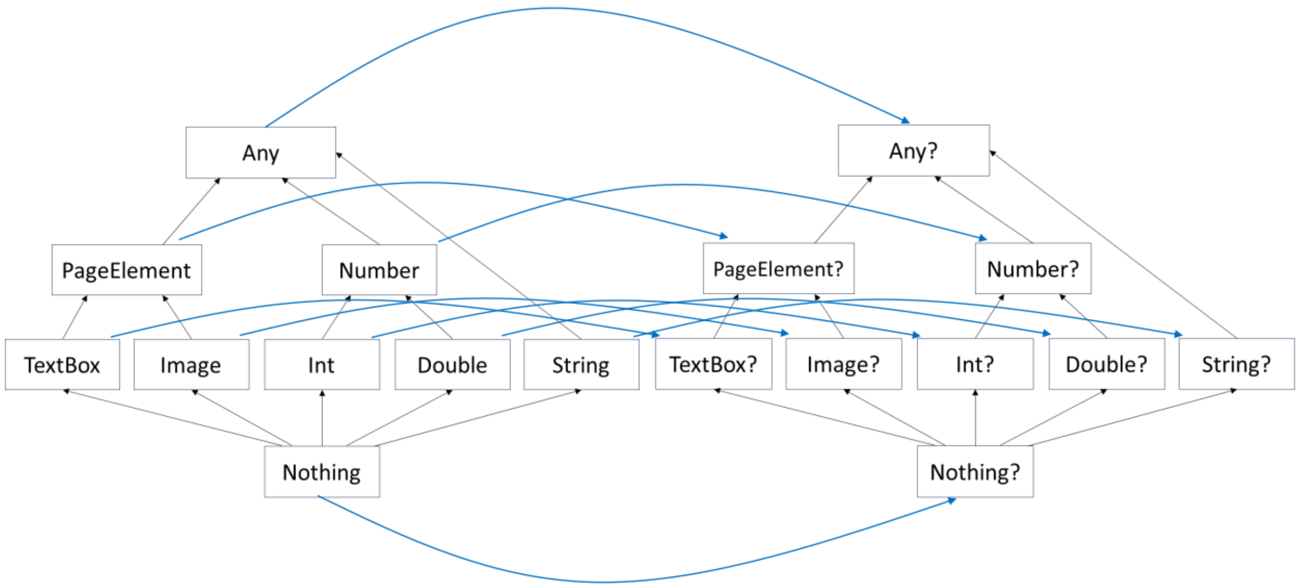
Compile error: Type mismatch.
Required:
String
Found:
Nothing?

Type hierarchy









Subtyping: notation

Common to write <: to mean “is a subtype of”, and :> to mean “is a supertype of”

Passing subtypes as parameters

Rule: if a function requires a parameter of type T, it is OK to pass an argument of type U <: T

```
fun foo(n: Number) {
    ...
}

fun main() {
    val i: Int = 42
    foo(i)
}
```

OK: Int <: Number

Receiving a return value into a supertype

Rule: if a function returns a parameter of type U, it is OK to receive this into a variable or property of type T :> U

```
fun produceString(): String = ...

fun main() {
    var maybeString: String? = null
    maybeString = produceString()
}
```

OK: String? :> String

Subtyping in action: assigning to a property or variable

Rule: in an assignment statement of the form $x = e$, the type of e must be a subtype of the type of x

```
class SmartHome {
    private var lamp: Lamp = Lamp(isOn = true)

    fun upgradeLamp () {
        lamp = DimmingLamp(isOn = true)
    }
}
```

OK: `DimmingLamp` <: `Lamp`

Late binding

```
fun manipulateLamp(lamp: Lamp) {
        … lamp.pressSwitch() …
}
```

Which method should be called?

- `pressSwitch` from `Lamp`?
- `pressSwitch` from `DimmingLamp`?
- `pressSwitch` from some other `Lamp` subclass?

The method that should be called depends on the type of the object to which `lamp` refers **when the program runs**

Determining which method to call based on the runtime type of an object is called late binding.

Binding: the link between the method name in the source code and the code of the method that should be executed

Late: the binding is not determined when the program is compiled – it is determined later, when the program is running

Apparent vs. actual types

Apparent type of an object reference: the type provided in the declaration (or the type inferred by the compiler)

Actual type of an object reference: the type of the object to which the reference refers when the program is running

Apparent type never changes: the types of declarations are fixed
Actual type can change if the reference gets re-assigned
Actual type is always a subtype of apparent type

Apparent vs. actual types: example

```
fun main(args: Array<String>) {
    val lamp1: Lamp = Lamp(isOn = true)
```

Apparent type of `lamp1` is `Lamp` – provided in declaration
Actual type of `lamp1` is `Lamp`, due to `Lamp` constructor

```
fun main(args: Array<String>) {
    val lamp1: Lamp = Lamp(isOn = true)
    var lamp2 = Lamp(isOn = false)
```

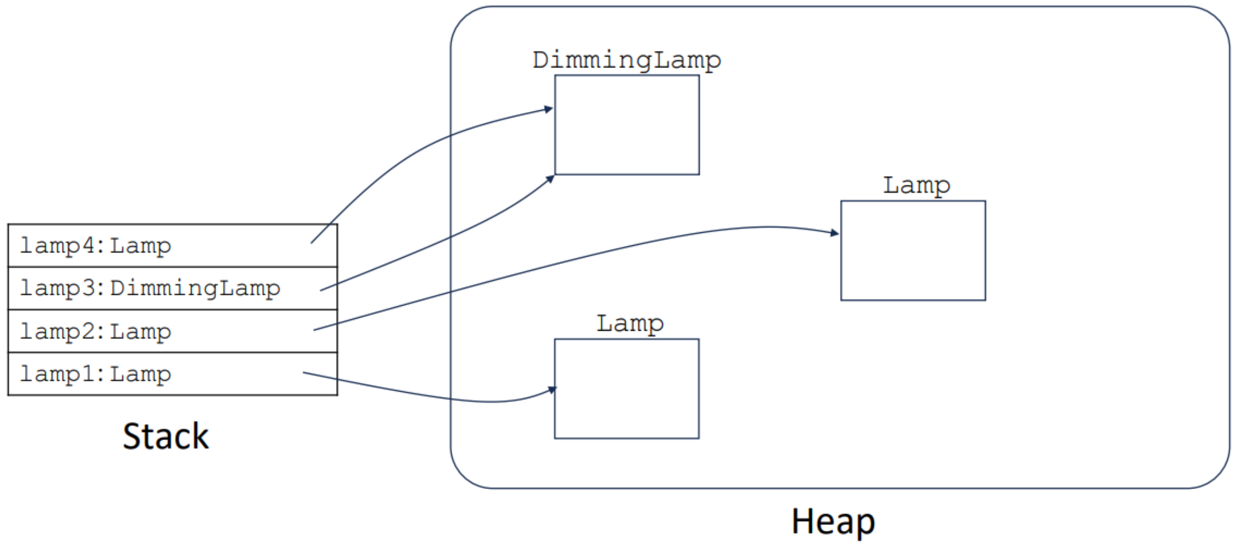
Apparent type of `lamp2` is `Lamp` – inferred by compiler
Actual type of `lamp2` is `Lamp`, due to `Lamp` constructor

```
fun main(args: Array<String>) {
    val lamp1: Lamp = Lamp(isOn = true)
    var lamp2 = Lamp(isOn = false)
    val lamp3 = DimmingLamp(isOn = true)
```

Apparent type of `lamp3` is `DimmingLamp` – inferred by compiler
Actual type of `lamp3` is `DimmingLamp`, due to `DimmingLamp` constructor

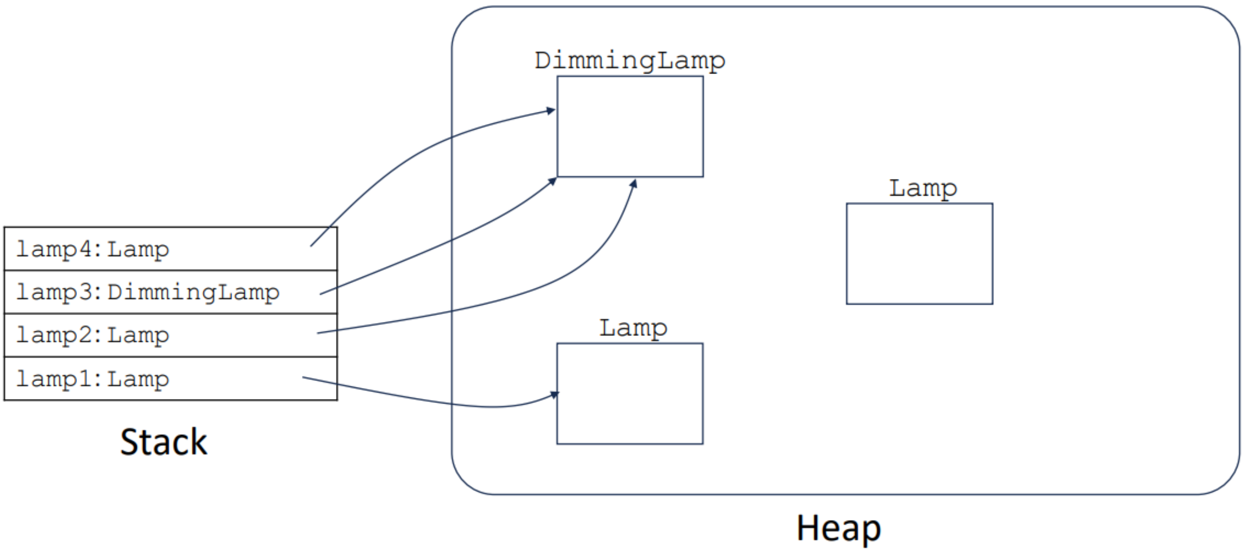
```
fun main(args: Array<String>) {
    val lamp1: Lamp = Lamp(isOn = true)
    var lamp2 = Lamp(isOn = false)
    val lamp3 = DimmingLamp(isOn = true)
    val lamp4: Lamp = lamp3
```

Apparent type of `lamp4` is `Lamp` – provided in declaration
Actual type of `lamp4` is `DimmingLamp`: it refers to the same `DimmingLamp` as lamp3




```
fun main(args: Array<String>) {
    val lamp1: Lamp = Lamp(isOn = true)
    var lamp2 = Lamp(isOn = false)
    val lamp3 = DimmingLamp(isOn = true)
    val lamp4: Lamp = lamp3
    // What do stack and heap look like here?
    lamp2 = lamp3
    // What do stack and heap look like here?
}
```

Actual type of `lamp2` has changed to `DimmingLamp`: `lamp2` has been reassigned to refer to a different object



Apparent types and properties / methods

Properties and methods are available based on **apparent type**

Apparent type: `Lamp`

Actual type: `DimmingLamp`

```
val lamp: Lamp = DimmingLamp(isOn = true)
lamp.pressSwitch()
lamp.down()
```

OK: apparent type (`Lamp`) provides method `pressSwitch`

Compile error: apparent type (`Lamp`) does not provide method `down`

```
fun main() {
    var lamp = Lamp(isOn = true)
    println(lamp)
    lamp.pressSwitch()
    println(lamp)
    // l.down() // Compile error
    val dimmingLamp = DimmingLamp(isOn = false)
    println(dimmingLamp)
    dimmingLamp.pressSwitch()
    dimmingLamp.down()
    println(dimmingLamp)
    lamp = DimmingLamp(isOn = false)
    println(lamp)
    lamp.pressSwitch()
    println(lamp)
    // l.down() // Compile error
}
```

Output:

```
LIGHT
(darkness)
(darkness)
LIGHT: *********
(darkness)
LIGHT: **********
```

Late binding again

```
fun manipulateLamp(lamp: Lamp) {
    …
    lamp.pressSwitch()
    …
}
```

Which method should be called?

`pressSwitch` from `Lamp`?

`pressSwitch` from DimmingLamp?

`pressSwitch` from some other `Lamp` subclass?

At runtime, the actual type of `lamp` is used to determine which version of the `pressSwitch` method to call

Late binding is also called dynamic method dispatch (or just dynamic dispatch)
Method dispatch: the process of determining which code should execute in response to a method call
Dynamic method dispatch: the code to be executed is determined at runtime – i.e., based on dynamic information
Static method dispatch: the code to be executed is already determined when the program is compiled – based purely on static information

Static = "at compile time"
Dynamic = "at runtime"

Dynamic vs. static dispatch

Static dispatch is slightly more efficient than dynamic dispatch:

- Statically dispatched call: program counter is set to the start address of the method
- Dynamically dispatched call: start address of the required method is determined based on object's actual type; then program counter is set to this address

Static method dispatch in Kotlin

A method call can be statically dispatched if the method is not abstract, and there is no possibility of the method being overridden

This is applies to:

- Top level functions
- Final methods (the default)
- Private methods

Careful: extension methods use static dispatch based on apparent type

```
open class A {
    open fun sayHello()
        = println("Hello from A")
}

class B : A() {
    override fun sayHello()
        = println("Hello from B")
}

fun A.sayGoodbye()
    = println("Goodbye from A")

fun B.sayGoodbye()
    = println("Goodbye from B")
```

```
fun main() {
    val myA: A = B()
    val myB: B = B()
    myA.sayHello()
    myB.sayHello()
    myA.sayGoodbye()
    myB.sayGoodbye()
}
```

Dynamic dispatch: actual type is B

Static dispatch: apparent type is A

Output:

```
Hello from B
Hello from B
Goodbye from A
Goodbye from B
```

Programming against an interface

Best practice: program against interfaces

Example: when you need a mutable list property, use `MutableList` as apparent type for the property:

```kotlin
class DataStore {
    private val data: MutableList<Int> = ArrayList()
    …
}

class DataStore {
    private val data: MutableList<Int> = LinkedList()
    …
}

class DataStore {
    private val data: MutableList<Int> = mutableListOf()
    …
}
```

All fine: the apparent type is `MutableList`.

Do not use a more specific type as apparent type.

```kotlin
class DataStore {
    private val data: ArrayList<Int> = ArrayList()
    …
}
```

Bad: apparent type is `ArrayList`, an implementing class

```kotlin
class DataStore {
    private val data = LinkedList()
    …
}
```

Bad: apparent type is (inferred to be) `LinkedList`, an implementing class

Why not?

- If your code only depends on the service provided by the interface, your code is more flexible
- By using `MutableList` as apparent type, we cannot write code that accidentally depends on methods only provided by e.g. `ArrayList`
- This makes it trivial to change our code to use a different kind of list:

```kotlin
class DataStore {
    private val data: MutableList<Int> = ArrayList() LinkedList()
    …
}
```

No other changes needed: data only offered the `MutableList` service, which `LinkedList` provides.

```
fun filterBadWords(
    wordList: ArrayList<String>,
    badWords: Set<String>,
): List<String> = wordList.filter { it !in badWords }
```

This is bad: It has been programmed against a specific kind of list: `ArrayList`. The function is thus limited to filtering `ArrayList`s.

Better:

```
fun filterBadWords(
    wordList: List<String>,
    badWords: Set<String>,
): List<String> = wordList.filter { it !in badWords }
```

Now the function is programmed against the `List` interface. The function can filter any kind of `List`.

But … don't implementing classes provide added value?

Example:

- `ArrayList` provides an `ArrayList`-specific method, `trimToSize`
- `trimToSize` resizes the list so that its capacity matches the current list size – gets rid of spare capacity
- This can save memory if list is not expected to grow in the future

We cannot call `trimToSize` if we program strictly against the `MutableList` interface. The interface does not offer `trimToSize` as part of its service.

Solution: `is` and smart casts

```
class DataManager {
    val lotsOfData: MutableList<MutableList<String>>
        = mutableListOf()

    ...

    fun finaliseData() {
        for (list in lotsOfData) {

            list.trimToSize()

        }
    }
}
```

Compile error: Unresolved reference: trimToSize

```
class DataManager {
    val lotsOfData: MutableList<MutableList<String>>
        = mutableListOf()

    ...

    fun finaliseData() {
        for (list in lotsOfData) {
            if (list is ArrayList) {
                list.trimToSize()
            }
        }
    }
}
```

Check whether **actual type** of `list` is `ArrayList`

Control only reaches here if actual type is `ArrayList`, so `list` can be used with **apparent type** `ArrayList` – this is a **smart cast**

Equivalently...

```
class DataManager {
    val lotsOfData: MutableList<MutableList<String>>
        = mutableListOf()

    ...

    for (list in lotsOfData) {
        if (list !is ArrayList) {
            continue
        }
        list.trimToSize()
    }
}
```

Check whether **actual type** of `list` is `ArrayList`

Control only reaches here if actual type is `ArrayList`, so `list` can be used with **apparent type** `ArrayList` – this is a **smart cast**

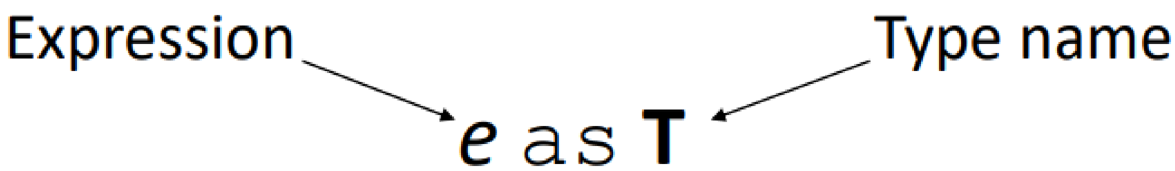
Limits of smart casts

```
class SmartHome {
        private var lamp: Lamp = Lamp(isOn = true)
        fun lowerBrightness(notches: Int) {
                if (lamp is DimmingLamp) {
                        for (i in 1..notches) {
                                lamp.down()
                        }
                }
        }
        fun updateLamp(newLamp: Lamp) {
                lamp = newLamp
        }
}
```

Compile error: Smart cast to '`DimmingLamp`' is impossible, because '`lamp`' is a mutable property that could have been changed by this time

Downcasting, via `as`

If you are sure the actual type of an object reference will be some more specific subtype, you can use as to downcast the object reference to the more specific type



Throws a `ClassCastException` if actual type of e is not a subtype of T

Otherwise: has no effect on e, but the expression (`e as T`) has apparent type T
This allows access to the T-specific services of e

Using a downcast

```
class SmartHome {
    private var lamp: Lamp = Lamp(isOn = true)

    fun lowerBrigtness(notches: Int) {
        if (lamp is DimmingLamp) {
            for (i in 1..notches) {
                (lamp as DimmingLamp).down()
            }
        }
    }

    fun updateLamp(newLamp: Lamp) {
        lamp = newLamp
    }
}
```

Downcast: fails with `ClassCastException` if used incorrectly
Apparent type is `DimmingLamp`, so `down` is available

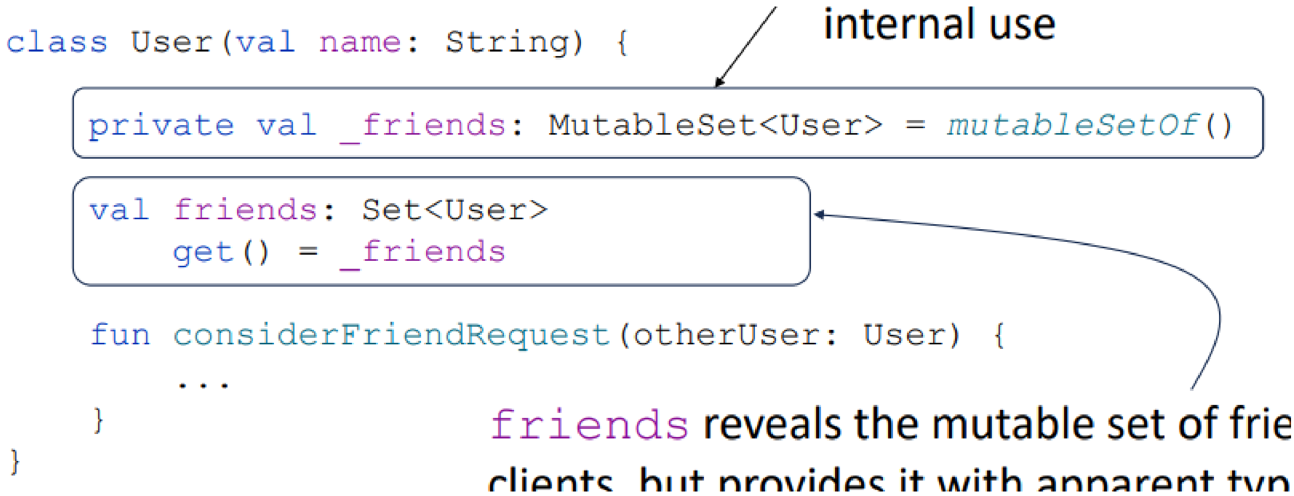
Design challenge

A `User` has a set of friends that can change over time

- Part of the service `User` provides: reveal who its set of friends are
- Not part of the `User` service: allow clients to modify this set

How should a `User`'s friends be modelled using properties?

Option 1: provide read-only view of mutable data

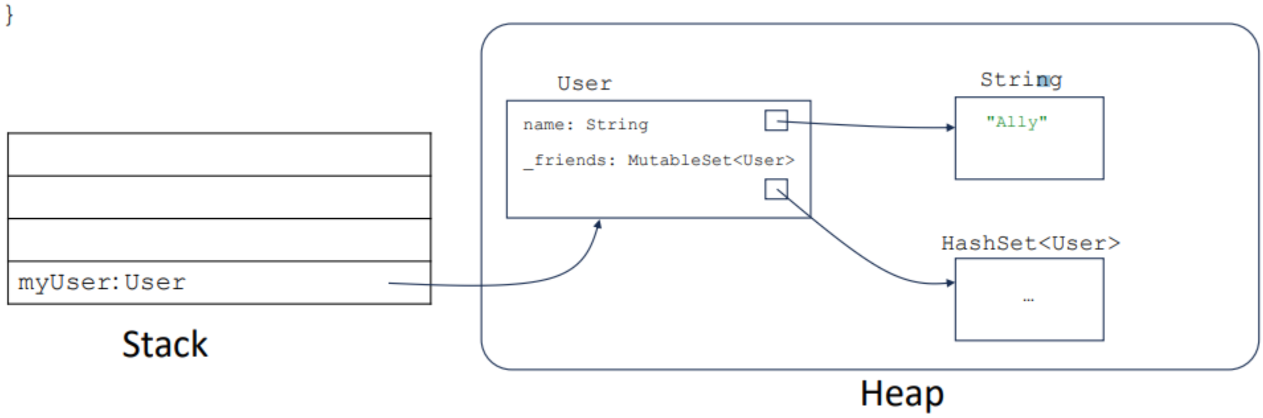


`_friends` equips a `User` with a mutable set of friends for internal use.

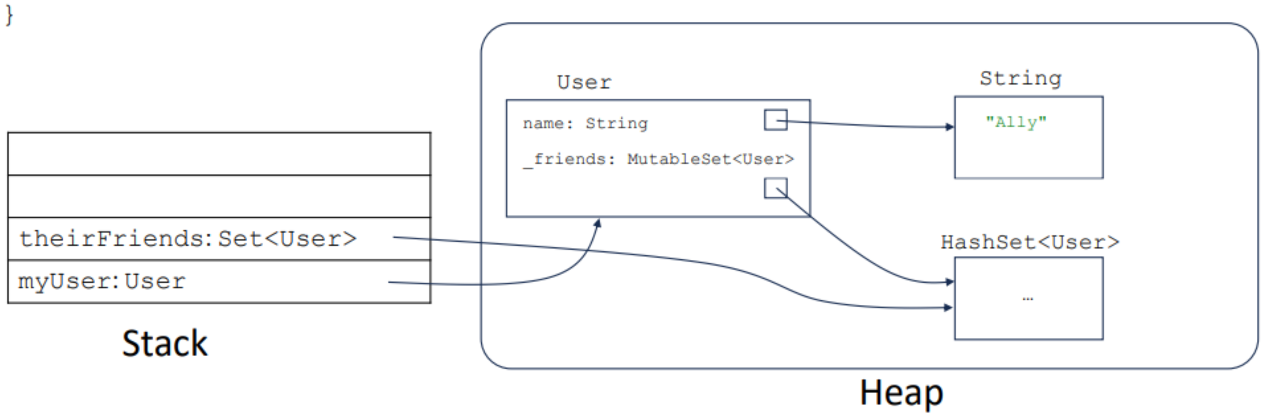
`friends` reveals the mutable set of friends to clients, but provides it with apparent type Set – the mutable part of the set's service is hidden.

This design does not duplicate the `_friends` set

```
fun main() {
    val myUser = User("Ally")
    …

}
```



```
fun main() {
    val myUser = User("Ally")
    …
    val theirFriends = myUser.friends
}
```



Option 2: return a copy

internal use

```
class User(val name: String) {
    private val _friends: MutableSet<User> = mutableSetOf()
    val friends: Set<User>
        get() = _friends.toSet()

    fun considerFriendRequest(otherUser: User) {
        ...
    }
```

`_friends` equips a `User` with a mutable set of friends for internal use

`friends` yields a new set that contains all the Users in `_friends`

Option 3: return the set via a protective wrapper

internal use

```
class User(val name: String) {
    private val _friends: MutableSet<User> = mutableSetOf()
    val friends: Set<User>
        get() = Collections.unmodifiableSet(_friends)

    fun considerFriendRequest(otherUser: User) {
        ...
```

`_friends` equips a `User` with a mutable set of friends for internal use `friends` yields an object that wraps `_friends` and rejects any mutating calls

Overriding properties

With inheritance, we have focused on subclasses overriding methods. However, properties can be overridden too.

A `Cell` class – wraps a value of some type

```
open class Cell<T>(open var value: T) {
    override fun toString(): String {
        return "[$value]"
    }
}
```

Allows `Cell` to have subclasses
Allows the value property to be overridden

`BackedUpCell` subclass – allows previous cell values to be restored

```
class BackedUpCell<T>(value: T) : Cell<T>(value) {
    private val backups: MutableList<T> = mutableListOf()

    override var value: T
        get() = super.value
        set(value) {
            backups.add(0, super.value)
            super.value = value
        }

    fun restore() {
        if (!backups.isEmpty()) {
            super.value = backups.removeAt(0)
        }
    }
}
```

Overriding the `value` property

Exercise: why is it important to use `super` here?

Alternatives to inheritance

Inheritance can be useful, but is not always the best approach.

Let us look at an alternative way to model `GridWorld`s that avoids inheritance

Remember the `GridWorld` abstract class?

```
abstract class GridWorld(…) {
    …
    private fun updatePosition(newPosition: Pair<Int, Int>) {
        …
        position = handleOverrun(newPosition)
    }
    protected abstract fun handleOverrun(newPosition: Pair<Int, Int>): Pair<Int, Int>
    …
}
```

Details of how to handle overruns left abstract: subclasses fill them in

```
class BoundedGridWorld(…) : GridWorld(…) {
    override fun handleOverrun(newPosition: Pair<Int, Int>): Pair<Int, Int> =
        Pair(
            first = max(0, min(newPosition.first, height - 1)),
            second = max(0, min(newPosition.second, width - 1)),
        )
}
```

One example of a subclass “filling in the blanks”

Alternative design

Have just one `GridWorld` class – not abstract, not open

Equip this class with a `handleOverrun` property: a function that determines how overruns should be handled

A function property that parameterises a class is called a **strategy**

`GridWorld` using a strategy

overruns

```
class GridWorld(
    private val width: Int,
    private val height: Int,
    private val handleOverrun: (Pair<Int, Int>) -> Pair<Int, Int>,
) {
    private val grid: Array<Array<Terrain>> = randomTerrain()
    private var position: Pair<Int, Int> = randomPosition()

    fun up() = updatePosition(position.copy(second = position.second + 1))

    fun down() = updatePosition(position.copy(second = position.second - 1))

    // left() and right() - similar

    private fun updatePosition(newPosition: Pair<Int, Int>) {
        if (newPosition.first in 0..<width &&
            newPosition.second in 0..<height) {
            position = newPosition
            return
        }
        position = handleOverrun(newPosition)
    }
    …
}
```

Invoke the strategy method to handle a potential overrun

Strategy for handling overruns

Creating specific `GridWorld`s

Aside: functions used to create object instances are called **factories**

```
fun createBoundedGridWorld(width: Int, height: Int): GridWorld =
    GridWorld(width, height) {
        Pair(
            first = max(0, min(it.first, height - 1)),
            second = max(0, min(it.second, width - 1)),
        )
    }

fun createDeadlyGridWorld(width: Int, height: Int): GridWorld =
    GridWorld(width, height) {
        throw DeadPlayerException("Fell off world!")
    }
```

Easy: pass a suitable strategy

Strategies are greater!