

Data
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Hogeschool Rotterdam
Rotterdam, Netherlands

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Lecture topics

- Mechanism of abstraction
- The need for data structures
- Classes as data structures in Python
- Tuples and records

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Introduction

- The big issue of the whole course is **abstraction** in programming
- Abstraction is a fundamental concept in programming to reduce repetition
- We sit atop a mountain of abstraction, which we make taller at every iteration

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Grab the student next to you

- Describe what you just did so that someone else can perform the same action

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Grab the student next to you

- Describe what you just did so that someone else can perform the same action
- Now add specific details about the movements of your arm and phalanges (pieces of fingers)

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Grab the student next to you

- Describe what you just did so that someone else can perform the same action
- Now add specific details about the movements of your arm and phalanges (pieces of fingers)
- Now realize that there are even more subcomponents: individual muscles, tendons, etc.

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Grab the student next to you

- Describe what you just did so that someone else can perform the same action
- Now add specific details about the movements of your arm and phalanges (pieces of fingers)
- Now realize that there are even more subcomponents: individual muscles, tendons, etc.
- But then we have also cells that make these up
- ...

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Human love for abstraction

- Our brain cannot handle so many details
- To cope with this, we are structured in layers
- Our consciousness manipulates only the upper layers with simple instructions
- *Raise arm above head*

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Human love for abstraction

- The same happens with regular language
- “*Go buy a liter of milk*” is quite a short description
- The underlying operation is very complex

Complexity of simple instructions

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```
1  Go buy a liter of milk =  
2    Turn game off  
3    Get up from the couch  
4    Curse the instruction giver  
5    Get dressed  
6    Put money in pocket  
7    Leave house  
8    Reach nearest shop  
9    Enter shop  
10   Find milk  
11   Take one liter bottle  
12   Pay milk  
13   Go home  
14   Give milk to instruction giver
```

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Human love for abstraction

- And clearly something like “*reach nearest shop*” is not a trivial instruction by itself
- Think about all the things you give for granted
 - Crossing roads
 - Traffic lights
 - Pathfinding
 - Road work and obstructions
 - Use of transportation methods
 - ...

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Flying back to Earth

- How is this relevant for programmers?
- We have a similar issue with a modern computer

A single Python instruction runs

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```
1 +-----+
2 | VM instructions |
3 +-----+
4 | Machine instruction |
5 +-----+
6 | CPU components      |
7 +-----+
8 | Logic gates          |
9 +-----+
10 ...
```


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Flying back to Earth

- Moreover, sometimes we have repetition of constructs in our own code
- This means that we would like to extend the pyramid with our own stuff

A single Python program runs

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```
1 +-----+
2 | Own stuff |
3 +-----+
4 | VM instructions |
5 +-----+
6 | Machine instruction |
7 +-----+
8 | CPU components |
9 +-----+
10 | Logic gates |
11 +-----+
12 ...
```

What kind of “own stuff”?

- Any recurring structure, code, etc.
- We do not want to repeat it every time
- We just give it a name, instead of specifying it every time
- The actual goal is to make things simpler
 - Code reuse, maintainability, etc. do not exist
 - It is all just **properly built abstractions that make reasoning about code easier**

Repeated code

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```
1 playerOneName = "P1"  
2 playerOnePositionX = 0.0  
3 playerOnePositionY = 0.0  
4  
5 playerTwoName = "P2"  
6 playerTwoPositionX = 5.0  
7 playerTwoPositionY = 0.0  
8  
9 playerThreeName = "P3"  
10 playerThreePositionX = 10.0  
11 playerThreePositionY = 0.0
```

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```
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5 playerTwoName = "P2"  
6 playerTwoPositionX = 5.0  
7 playerTwoPositionY = 0.0  
8  
9 playerThreeName = "P3"  
10 playerThreePositionX = 10.0  
11 playerThreePositionY = 0.0
```

Now let's add a score, an exp level, etc.

Repeated code

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```
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8  
9 playerThreeName = "P3"  
10 playerThreePositionX = 10.0  
11 playerThreePositionY = 0.0
```

Now let's add a score, an exp level, etc.

Does it scale well?

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Make some examples

- Everyone make an example of repeated structures of data.
- Some of you will present theirs

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- A possible solution to this problem is capturing the repetition of data structures
- With a name, and a specification of what is common about them

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Fundamental ingredients of the solution

- Brains of the programmer, always active
- Abstraction requires awareness and experience
- It is as much technique as it is art

Repeated code

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```
1 playerOneName = "P1"  
2 playerOnePositionX = 0.0  
3 playerOnePositionY = 0.0  
4  
5 playerTwoName = "P2"  
6 playerTwoPositionX = 5.0  
7 playerTwoPositionY = 0.0  
8  
9 playerThreeName = "P3"  
10 playerThreePositionX = 10.0  
11 playerThreePositionY = 0.0
```

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Fundamental ingredients of the solution

- We observe that there is an underlying pattern, which we will call **abstraction**
- The pattern, or abstraction, comes repeated in several **concrete instances** in our program

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Fundamental ingredients of the solution

- We observe that there is an underlying pattern, which we will call **abstraction**
- The pattern, or abstraction, comes repeated in several **concrete instances** in our program
- In the program above this is fairly obvious, in real life not always really :)

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Fundamental ingredients of the solution

- A proper name for the abstraction
- **For example?**

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Fundamental ingredients of the solution

- A proper name for the abstraction
- **For example?** Player

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Fundamental ingredients of the solution

- A set of common attributes
- All characterizing aspects of the abstraction that are common to all its instances
- **For example?**

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Fundamental ingredients of the solution

- A set of common attributes
- All characterizing aspects of the abstraction that are common to all its instances
- **For example?** Name, PositionX, PositionY

The blueprint (**THIS IS NOT CODE!**)

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```
1 Abstraction Player =  
2   Name, which is a sequence of characters  
3   PositionX, which is a number  
4   PositionY, which is a number
```

The abstraction above is called a **data structure**.

It is not valid Python code, but it is a blueprint specifying a recurrent set of attributes that often go together to identify a player.

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How is this done in Python?

- Python offers a facility called `class`
- It is used to capture a data structure.

Syntax of Python classes

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```
1 class <<Name>>:  
2     def __init__(self, <<v1>>, <<v2>>, ..., <<vN>>):  
3         self.<<A1>> = <<v1>>  
4         self.<<A2>> = <<v2>>  
5         ...  
6         self.<<AN>> = <<vN>>
```

The class has thus: name, initial values v_1 through v_N , and attributes A_1 through A_N initialized with `__init__`.

`self` is a reference to the concrete instance that is being set up.

Usage of Python classes

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```
1 x = <<Name>>(<<v1>>, <<v2>>, ..., <<vN>)
```

Sets up a concrete instance of <<Name>> with some initial values.

Usage of Python classes

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```
print(x.<<A2>>)
```

Prints the value of the second attribute of the concrete instance called `x` of class `<<Name>>`.

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```
x.<<A3>> = y
```

Assigns `y` as the new value of the third attribute of the concrete instance called `x` of class `<<Name>>`.

Semantics of Python classes

- The semantics of Python classes require a more sophisticated model of memory
- Memory is now divided in two

STACK The state that we used so far, for primitive values (`int`, `string`, etc.)

HEAP A storage for complex values such as classes

Semantics of Python classes

- An instruction I will now transform the initial heap and stack H, S into the resulting (possibly changed) heap and stack H', S' ^a

$$\langle PC, H, S \rangle \xrightarrow{I} \langle PC', H', S' \rangle$$

^ain addition to the program counter PC , which always behaves in the same way

Semantics of creation

- Consider creation of a Python class: `x = <<Name>>(...)` (shortened to `xName`)
- This affects both memories

HEAP We create and initialize a new instance of class `<<Name>>`

STACK We add an entry `x` to the stack, which references to the newly created instance

Semantics of creation

- Given that:
- $|H|$ is the size of the heap at creation, which we call the **address** of the new instance
- $\langle\langle Name \rangle\rangle(\dots)$ is a new instance of the class, which contains a map from the attribute names to their values

$$\langle PC, H, S \rangle \xrightarrow{xName} \langle PC + 1, H[|H| \mapsto \langle\langle Name \rangle\rangle(\dots)], S[x \mapsto |H|] \rangle$$

- x is, unsurprisingly, called a **reference**
 - it does not contain the value of the class instance
 - it merely tells us where to find it

Attribute lookup

- Consider reading an attribute (also called lookup)
- $x.<<A>>$ (shortened to xA)^a
- Where is it in memory?

STACK We find an entry x , which tells us where the corresponding instance of the class is found

HEAP We find the actual attribute in the map of attributes

$$\langle PC, H, S \rangle \xrightarrow{xA} H[S[x]][A]$$

^a

Attribute lookup

- Consider reading an attribute (also called lookup)
- $x.<<A>>$ (shortened to xA)^a
- Where is it in memory?

STACK We find an entry x , which tells us where the corresponding instance of the class is found

HEAP We find the actual attribute in the map of attributes

$$\langle PC, H, S \rangle \overset{xA}{\hookrightarrow} H[S[x]][A]$$

^aThis is not a full instruction, but an **expression**. For this reason, we use another kind of arrow, \hookrightarrow , to denote that we simply evaluate the expression but do not change the state of the program.

Attribute update

- Consider assigning to an attribute
- $x.\langle\langle A \rangle\rangle = v$ (shortened to xAv)
- Where is it in memory?

STACK We find an entry x , which tells us where the corresponding instance of the class is found

HEAP We reassign the actual attribute in the map of attributes

$$\langle PC, H, S \rangle \xrightarrow{xAv} \langle PC + 1, H[S[x] \mapsto H[S[x]][A \mapsto v]] \rangle$$

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Examples

- We can now implement our player data type
- We will use a Python class to do so
- We will then create concrete instances of it, and use them

The blueprint to implement

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```
1 Abstraction Player =  
2   Name, which is a string  
3   PositionX, which is a number  
4   PositionY, which is a number
```

The implemented class

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```
1 class Player:
2     def __init__(self, name, posX, posY):
3         self.Name = name
4         self.PositionX = posX
5         self.PositionY = posY
```

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```
1 playerOneName = "P1"  
2 playerOnePositionX = 0.0  
3 playerOnePositionY = 0.0  
4  
5 playerTwoName = "P2"  
6 playerTwoPositionX = 5.0  
7 playerTwoPositionY = 0.0  
8  
9 playerThreeName = "P3"  
10 playerThreePositionX = 10.0  
11 playerThreePositionY = 0.0
```

Becomes:

```
1 playerOne = Player("P1", 0.0, 0.0)  
2 playerTwo = Player("P2", 5.0, 0.0)  
3 playerThree = Player("P3", 10.0, 0.0)
```

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S

PC
1

H


```
1 playerOne   = Player("P1", 0.0, 0.0)
2 playerTwo   = Player("P2", 5.0, 0.0)
3 playerThree = Player("P3", 10.0, 0.0)
```

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S	PC
	1

H	

```
1 playerOne = Player("P1", 0.0, 0.0)
2 playerTwo = Player("P2", 5.0, 0.0)
3 playerThree = Player("P3", 10.0, 0.0)
```

S	PC	playerOne
	2	ref(0)

H	0
	[N \mapsto "P1"; PX \mapsto 0.0; PY \mapsto 0.0]

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S

PC	playerOne
2	ref(0)

H

0
$[N \mapsto "P1"; PX \mapsto 0.0; PY \mapsto 0.0]$

```
1 playerOne = Player("P1", 0.0, 0.0)
2 playerTwo = Player("P2", 5.0, 0.0)
3 playerThree = Player("P3", 10.0, 0.0)
```

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S	PC	playerOne
	2	ref(0)

H	0	
	[N \mapsto "P1"; PX \mapsto 0.0; PY \mapsto 0.0]	

```
1 playerOne = Player("P1", 0.0, 0.0)
2 playerTwo = Player("P2", 5.0, 0.0)
3 playerThree = Player("P3", 10.0, 0.0)
```

S	PC	playerOne	playerTwo
	3	ref(0)	ref(1)

H	0	1
	...	[N \mapsto "P2"; PX \mapsto 5.0; PY \mapsto 0.0]

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S	PC	playerOne	playerTwo
	3	ref(0)	ref(1)

H	0	1
	...	[N \mapsto "P2"; PX \mapsto 5.0; PY \mapsto 0.0]

```
1 playerOne = Player("P1", 0.0, 0.0)
2 playerTwo = Player("P2", 5.0, 0.0)
3 playerThree = Player("P3", 10.0, 0.0)
```


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S	PC	playerOne	playerTwo
	3	ref(0)	ref(1)

H	0	1
	...	[N \mapsto "P2"; PX \mapsto 5.0; PY \mapsto 0.0]

```
1 playerOne = Player("P1", 0.0, 0.0)
2 playerTwo = Player("P2", 5.0, 0.0)
3 playerThree = Player("P3", 10.0, 0.0)
```

S	PC	playerOne	playerTwo	playerThree
	4	ref(0)	ref(1)	ref(2)

H	0	1	2
	[N \mapsto "P3"; PX \mapsto 10.0; PY \mapsto 0.0]

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Suppose we wish to access `playerOne.PositionX`

S	PC	playerOne	playerTwo	playerThree
	4	ref(0)	ref(1)	ref(2)

H	0			1	2
	[N \mapsto "P1"; PX \mapsto 0.0; PY \mapsto 0.0]		

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Suppose we wish to access `playerOne.PositionX`

S	PC	playerOne	playerTwo	playerThree
	4	ref(0)	ref(1)	ref(2)

H	0	1	2
	[N \mapsto "P1"; PX \mapsto 0.0; PY \mapsto 0.0]

First we look in the stack:

S	PC	playerOne	playerTwo	playerThree
	5	ref(0)	ref(1)	ref(2)

H	0	1	2
	[N \mapsto "P1"; PX \mapsto 0.0; PY \mapsto 0.0]

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Suppose we wish to access `playerOne.PositionX`

S	PC	playerOne	playerTwo	playerThree
	5	<code>ref(0)</code>	<code>ref(1)</code>	<code>ref(2)</code>

H	0			1	2
	<code>[N ↦ "P1"; PX ↦ 0.0; PY ↦ 0.0]</code>		

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Suppose we wish to access `playerOne.PositionX`

S	PC	playerOne	playerTwo	playerThree
	5	<code>ref(0)</code>	<code>ref(1)</code>	<code>ref(2)</code>

H	0	1	2
	<code>[N ↦ "P1"; PX ↦ 0.0; PY ↦ 0.0]</code>

Then we look in the heap:

S	PC	playerOne	playerTwo	playerThree
	5	<code>ref(0)</code>	<code>ref(1)</code>	<code>ref(2)</code>

H	0	1	2
	<code>[N ↦ "P1"; PX ↦ 0.0; PY ↦ 0.0]</code>

Using the concrete instances

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Suppose we wish to access `playerOne.PositionX`

S	PC	playerOne	playerTwo	playerThree
	5	ref(0)	ref(1)	ref(2)

H	0			1	2
	[N \mapsto "P1"; PX \mapsto 0.0; PY \mapsto 0.0]		

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Suppose we wish to access `playerOne.PositionX`

S	PC	playerOne	playerTwo	playerThree
	5	ref(0)	ref(1)	ref(2)

H	0			1	2
	[N \mapsto "P1"; PX \mapsto 0.0; PY \mapsto 0.0]		

Finally we search the right attribute (`PositionX`):

S	PC	playerOne	playerTwo	playerThree
	5	ref(0)	ref(1)	ref(2)

H	0			1	2
	[N \mapsto "P1"; PX \mapsto 0.0 ; PY \mapsto 0.0]		

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Are we there yet?

- We can keep extending our knowledge about the problem
- For example, we might notice that `PositionX` and `PositionY` might happen in other places of the program
- **What could we do?**

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Are we there yet?

- We can keep extending our knowledge about the problem
- For example, we might notice that `PositionX` and `PositionY` might happen in other places of the program
- **What could we do?**
- We could define a `Point2D` (or `Vector2D`) data structure!

```
1 class Vector2:
2     def __init__(self, x, y):
3         self.X = x
4         self.Y = y
5
6 class PlayerRefined:
7     def __init__(self, name, posX, posY):
8         self.Name = name
9         self.Position = Vector2(posX, posY)
```

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Refined data structures

- Creation is precisely identical to the previous sample
- The `__init__` of the `PlayerRefined` has the same inputs
- Where we had `playerOne = Player("P1", 0.0, 0.0)`
- Now we have `playerOne = PlayerRefined("P1", 0.0, 0.0)`

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Refined data structures

- Usage of the new player definition is almost identical to the previous
- Only changes are lookups like: `playerOne.PositionY`
- **What do they become now?**
- `playerOne.Position.Y`

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Refined data structures

- What does memory look like now with a player that contains a vector?
- Stack is similar to previous instance
- Heap contains a reference to a vector!

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S

PC
1

H

1

```
playerOne = PlayerRefined("P1", 0.0, 0.0)
```

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S	PC
	1

H	

1

```
playerOne = PlayerRefined("P1", 0.0, 0.0)
```

S	PC	playerOne
	2	ref(0)

H	0	1
	[N \mapsto "P1"; P \mapsto ref(1);]	[X \mapsto 0.0; Y \mapsto 0.0]

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What characterizes a good design of data structures?

- **Reuse** of code in places where otherwise repetition would happen
- **Encapsulation** of the semantics of the data structure
- **Loose coupling** between the data structure and the rest of the program

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Reuse of code

- Repetition is dangerous
- A small change in one place but not in the others can lead to unexpected consequences
- More code to read means more mental overhead
- Actual work of the program is hidden under lots of noise and thus less visible

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Encapsulation

- A data structure has a single, clear, well-defined goal
- Its name clearly explains what it contains and does
- There is no multiple functionality mix

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Encapsulation

- A data structure has a single, clear, well-defined goal
- Its name clearly explains what it contains and does
- There is no multiple functionality mix
- It's a cold beer, not a cocktail

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Loose coupling

- A data structure is a closed and complete unit
- To use it, you just need to declare it and initialize it
- The rest of the program integrates a well-designed data structure with minimal modification

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How do we verify all this?!?

- Takes experience and good taste
- It is an old story
- Remember: you have the power to make your own life a living Hell...

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How do we verify all this?!?

- Takes experience and good taste
- It is an old story
- Remember: you have the power to make your own life a living Hell...
- ...unless you reason first and write code after

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Build, in class, a series of data structures

- Tyre
- Wheel
- Engine
- Seat
- Light
- Person (driver and passenger)
- Car

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Lecture topics

- Abstraction is the fundamental mechanism that allows us to group concepts together and refer to them as if they were a single concept
- For example, a name and two numbers became a player
- We then use the new concept (the player) without having to explicitly mention all of its components every time
- This makes it leaner for us to manipulate complex programs, as less concepts (“actors”) make an appearance

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The best of luck, and thanks for the
attention!