# Functional Programming in Typed Racket

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# GitHub Course Page

All slides and course materials are available on:

https://github.com/fbie/parallel-functional-lectures

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- Used in financial industry, modern compilers and more.
- Jobs in functional programming pay better!

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- Racket is dynamically typed, Typed Racket has a static, strong type system.
- Functional language, no side-effects (mostly).
- Good for meta-programming (we won't look at that).

# Hello World in Typed Racket

```
;; This is a comment!
;; Tell the run-time, which language to use.
#lang typed/racket

;; Now, print something.
(print "Nihao!")
```

# A More Interesting Program

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;; Define x as the result of the computation.
(define x (* (+ 2 4) (+ 42 9)))
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We can check its value in the interactive mode:

```
> x
59
```

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In Racket, all expressions are written like this:

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(function arg1 arg2 ... argN)
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|---|---|---|
| `(+ x y)` | $\Rightarrow$ | $x + y$ |
| `(> x y)` | $\Rightarrow$ | $x > y$ |
| `(/ x y)` | $\Rightarrow$ | $\frac{x}{y}$ |
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Some functions are **variadic**:

| | | |
|---|---|---|
| `(+ x y z)` | $\Rightarrow$ | $x + y + z$ |

# Local Bindings

Just like local variables in Java, but you can never change them!

```
#lang typed/racket

(let ([x (* 2 16)]
      [y (* 3 17)])
    (print (+ x y)))
```

What does this program do?

**Note:** You cannot reference `x` and `y` after the last closing parenthesis of the `let` expression!

# The Same Program in Java

```
public static void main(String[] args) {
  int x = 2 * 16;
  int y = 3 * 17;
  System.out.println(x + y);
}
```

# A First Function

```
#lang typed/racket

(: times-two (-> Number Number))
(define (times-two x)
  (* 2 x))
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Several new things on this slide:

- Functions need no return statement. Their return value is the last executed statement!
- Type annotations start with `:` and describe the type of a symbol.
- The type of `times-two` is *Number* $\rightarrow$ *Number*.

# Types in Typed Racket

We write the function type $A \rightarrow B$ as:

```
(-> A B)
```

where `A` is the parameter type and `B` is the return type.

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```
(-> A B C)
```

Which types are parameter types, which ones are return types?

# A Second Function

```
(: funny (-> Number Number))
(define (funny x)
  (if (< x 0)
      (- x)
      x))
```

# A Second Function

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(define (funny x)
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Conditionals have the form `(if B E1 E2)`.

# Polymorphic Types

Polymorphic types in Typed Racket are very explicit:

```
(: twice (All (A) (-> A (Pairof A A))))
(define (twice a)
  (cons a a))
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"For all types `A`, the type of `twice` is such that iff you pass it a value of some type `A` it will return a pair of type `A` $\times$ `A`."

It's just like generic types in Java!

# The Same Program in Java

```
public static Pairof<A, A> twice(A a) {
  return new Pairof<A, A>(a);
}
```

**Note:** There is no build-in pair type in Java :(

# State is Immutable!

You cannot change a variable's value. Instead, use **recursion**:

```
(: is-even? (-> Integer Boolean))
(define (is-even? n)
  (if (< 1 n)
      (is-even? (- n 2))
      (= n 0)))
```

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Now, we can call the function:

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> (is-even? 1)
#f
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```

Now, we can call the function:

```
> (is-even? 1)
#f

> (is-even? 2048)
#t
```

# The Same Program in Java

```
public static bool isEven(int n) {
  while (1 < n)
    n = n - 2;
  return n == 0;
}
```

# Pattern Matching

In functional languages, you can **decompose** values and structs using the `match` construct. This is called **pattern matching**.

```
(: is-even? (-> Integer Boolean))
(define (is-even? n)
  (match n
    [0 #t]
    [1 #f]
    [_ (is-even? (- n 2))]))
```

`_` means “any other value”. It must always come last!

# Anonymous Functions

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> ((lambda (x) x) 2)
2
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Here, we have defined a lambda expression and applied it to the value `2`. We call this function the **identity function**. The line above is equal to

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We will often come across lambda expressions in functional programming!

# Structs in Typed Racket

Structs are containers for values.

```
(struct (myNumberBox
                [v : Number]))

(struct (myNumberStringBox
                ([n : Number] [s : String])))
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```
(struct (myNumberBox
                [v : Number]))

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We can also use type polymorphism here:

```
(struct (A) (myPolyBox [value : A]))
```

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- You can download Racket from
  - `racket-lang.org`

# Java Equivalent to Maybe

```
public abstract class Maybe<A> {}

public class None<A> extends Maybe<A> {
  public None() {}
}
public class Some<A> extends Maybe<A> {
  public final A a;
  public Some(A a) {
    this.a = a;
  }
}
```

# Singly-Linked Cons List 1/2

```
(define xs (cons 'a (cons 'b
     (cons 'c (cons 'd (cons 'e '()))))))
```

# Singly-Linked Cons List 1/2

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(define xs (cons 'a (cons 'b
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Get the first element of `xs`, the “head”:

```
> (first xs)
'a
> (cdr xs)
'a
```

# Singly-Linked Cons List 1/2

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Get the first element of `xs`, the “head”:

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> (first xs)
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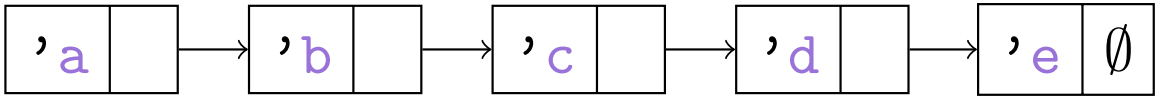
```

Get the remaining part of `xs`, the “tail”:

```
> (rest xs)
'('b 'c 'd 'e)
> (cdr xs)
'('b 'c 'd 'e)
```

# Singly-Linked Cons List 2/2

References to tail **cannot be changed**, because all **references are immutable**:



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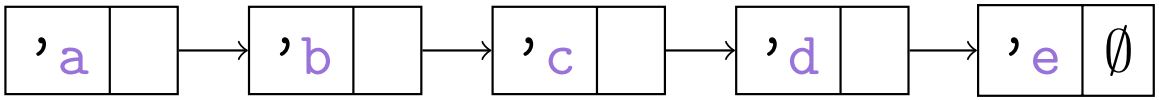


If we want to remove an element, we must build a new list, but we can re-use the tail of the element that we have deleted:

```
(remove xs 'c)
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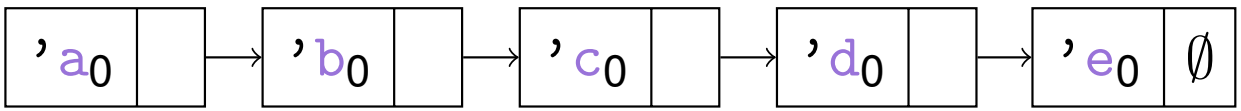

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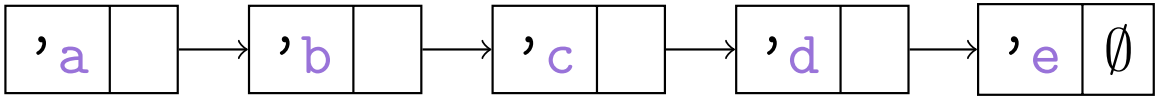


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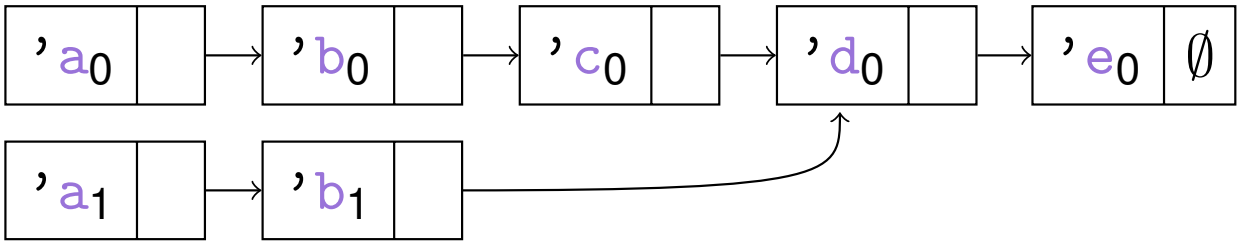

# Java Equivalent to Cons List

```
public abstract class LinkedList<A> {}

public class Nil<A> extends LinkedList<A> {
  public Nil() {}
}
public class Cons<A> extends LinkedList<A> {
  public final A a;
  public final LinkedList<A> tail;

  public Cons(A a, LinkedList<A> tail) {
    this.a = a;
    this.tail = tail;
  }
}
```

# Java Equivalent to Binary Tree

```
public abstract class BinaryTree<A> {}

public class Leaf<A> extends BinaryTree<A> {
  public final A a;
  public Leaf(A a) {
    this.a = a;
  }
}
public class Node<A> extends BinaryTree<A> {
  public final BinaryTree<A> left, right;
  public Node(BinaryTree<A> left,
              BinaryTree<A> right) {
    this.left = left; this.right = right;
  }
}
```

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- When would you prefer?

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