Ownership and Borrowing

Nicholas Matsakis


Hack without fear!

```ruby
class ::String
  def blank?
    /\A[[:space:]]*\z/ == self
  end
end
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Performance

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Performance

Ruby:
964K iter/sec

```c
static VALUE
rb_str_blank_as(VALUE str)
{
  rb_encoding *enc;
  char *s, *e;

  enc = STR_ENC_GET(str);
  s = RSTRING_PTR(str);
  if (!s || RSTRING_LEN(str) == 0) return Qtrue;

  e = RSTRING_END(str);
  while (s < e) {
    int n;
    unsigned int cc = rb_enc_codepoint_len(s, e, &n, enc);

    switch (cc) {
      case 9:
      case 0xa:
      case 0xb:
      case 0xc:
      case 0xd:
      case 0x20:
      case 0x85:
      case 0xa0:
      case 0x1680:
      case 0x2000:
      case 0x2001:
      case 0x2002:
      case 0x2003:
      case 0x2004:
      case 0x2005:
      case 0x2006:
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#if ruby_version_before_2_2()
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#endif
          /* found */
          break;
      default:
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    }
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  }
  return Qtrue;
}
```

https://github.com/SamSaffron/fast_blank

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964K iter/sec

10x!

C:
10.5M iter/sec

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```rust
extern “C” fn fast_blank(buf: Buf) -> bool {
  buf.as_slice().chars().all(|c| c.is_whitespace())
}
```

Performance

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Get Rust
string slice

Performance

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Get Rust string slice

Get iterator over each character

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Are all characters whitespace?

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Get Rust string slice

Get iterator over each character

Are all characters whitespace?

Performance

Ruby:
964K iter/sec

C:
10.5M iter/sec

Rust:
11M iter/sec

Parallel Programming

```
fn load_images(paths: &[PathBuf]) -> Vec<Image> {
    paths.iter()
         .map(|path| {
           Image::load(path)
         })
         .collect()
}
```

Parallel Programming

```
fn load_images(paths: &[PathBuf]) -> Vec<Image> {
    paths.iter()
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For each path…

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}
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For each path…

…load an image…

Parallel Programming

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fn load_images(paths: &[PathBuf]) -> Vec<Image> {
    paths.iter()
        .map(|path| {
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        })
        .collect()
}
```

For each path…

…load an image…

…create and return a vector.

Parallel Programming

```
extern crate rayon;
```

Parallel Programming

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Third-party library

Parallel Programming

```
extern crate rayon;
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Third-party library

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fn load_images(paths: &[PathBuf]) -> Vec<Image> {
    paths.par_iter()
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…make it parallel.

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           Image::load(path)
         })
         .collect()
}
```

…make it parallel.

Can also do: processes with channels, mutexes, non-blocking data structures…

Safer Parallel Programming

```
fn load_images(paths: &[PathBuf]) -> Vec<Image> {
    let mut jpegs = 0;
    paths.par_iter()
         .map(|path| {
           if path.ends_with(“jpeg”) { jpegs += 1; }
           Image::load(path)
         })
         .collect();
}
```

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Data-race

Safer Parallel Programming

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Will not compile

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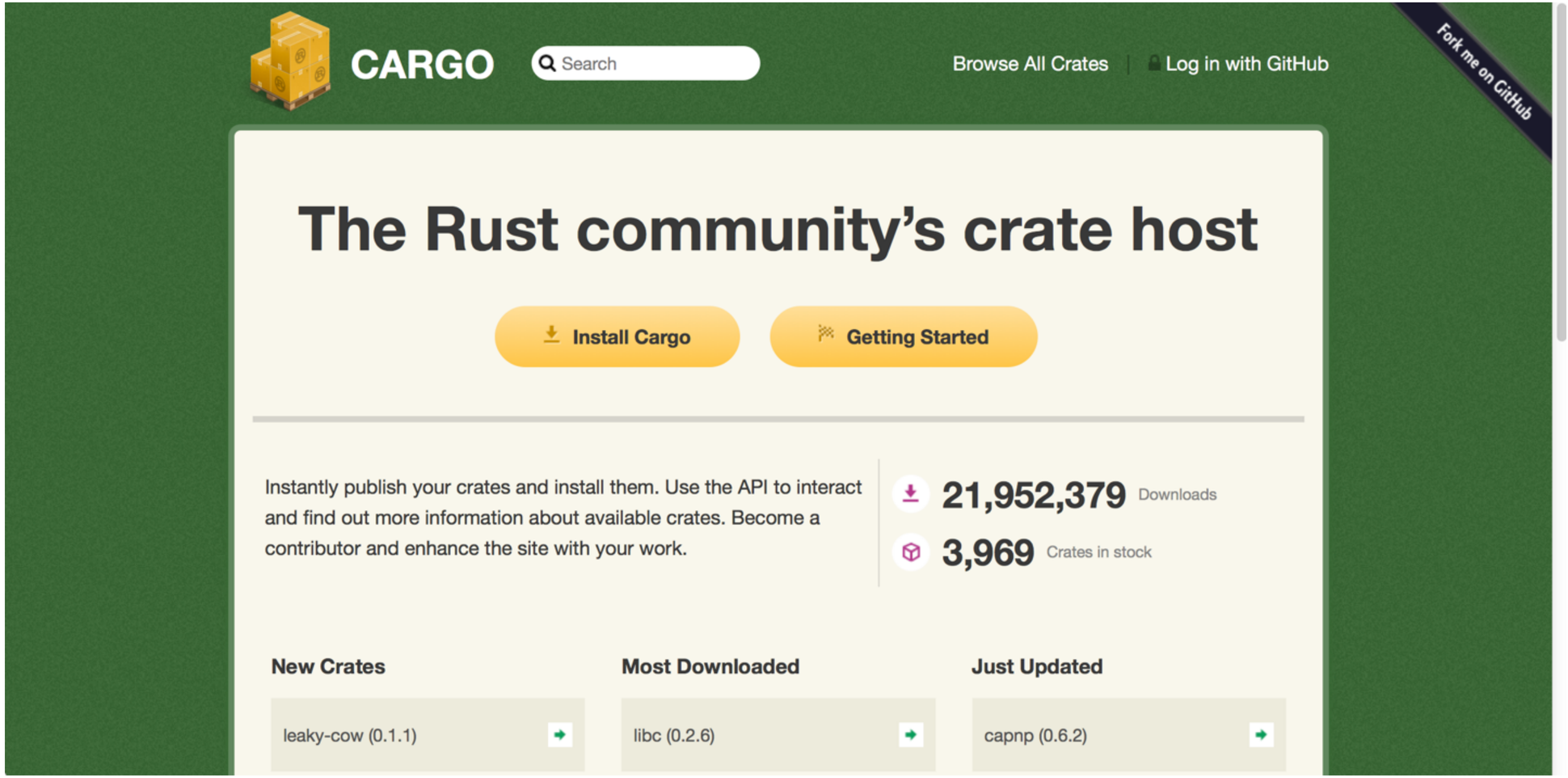
Data-race

Will not compile

To fix: use **AtomicU32, Mutex,** etc.

Cargo and crates.io



Open and welcoming

Rust has been **open source** from the beginning.

Open governance model based on **public RFCs**.

We have an **active, amazing community**.

Hello, world!

Hello, world!

```
fn main() {
  println!(“Hello, world!”);
}
```

Exercise: **hello world**

http://rust-tutorials.com/exercises/

Ownership

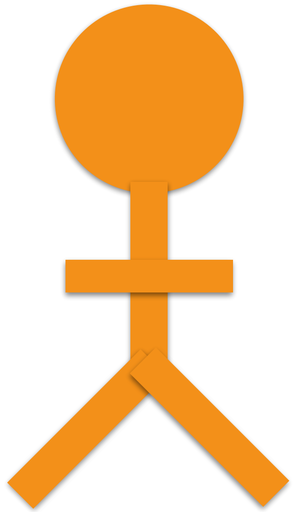
n. The act, state, or right of possessing something.

Borrow

v. To receive something with the promise of returning it.


Principles of Compiler Design
Alfred V. Aho
Jeffrey D. Ullman

Ownership

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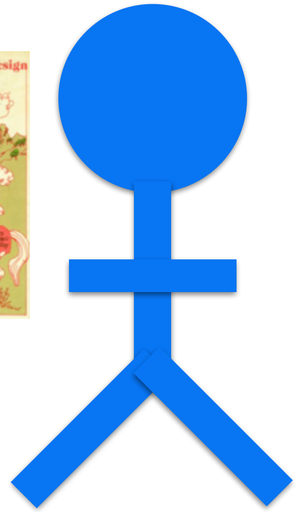

Ownership

```
fn main() {
  let name = format!("…");
  helper(name);
  helper(name);
}
```

```
fn helper(name: String) {
  println!(..);
}
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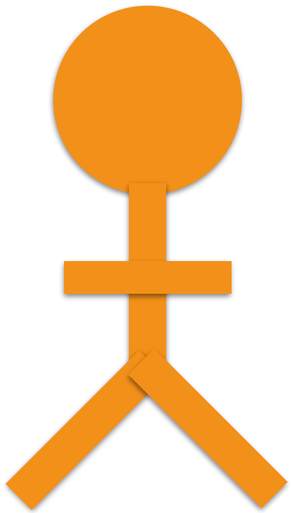

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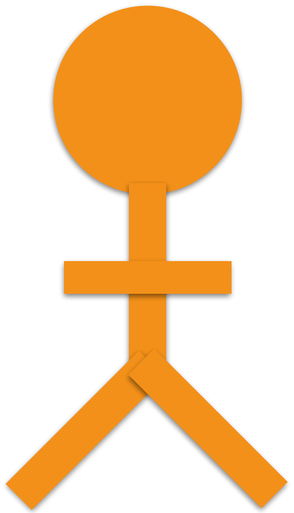

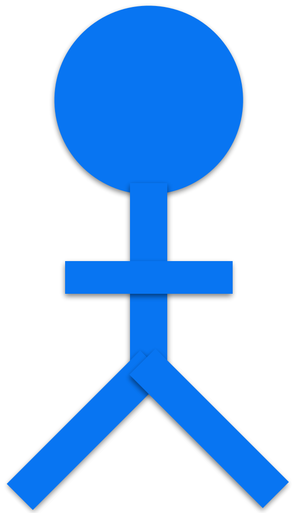

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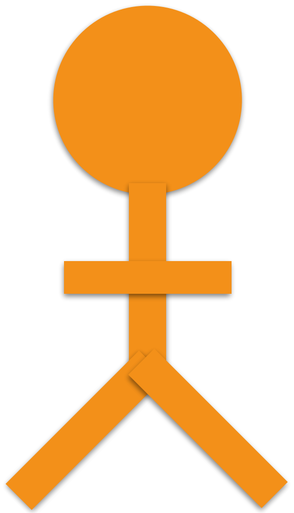
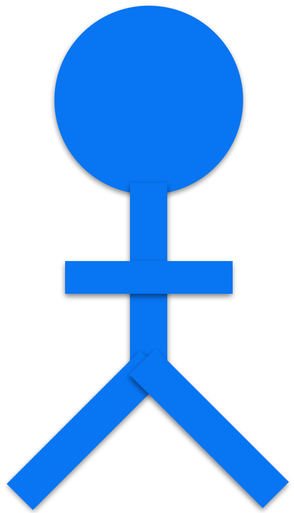
Take ownership of a String





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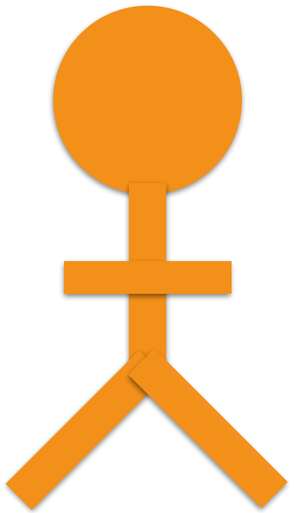

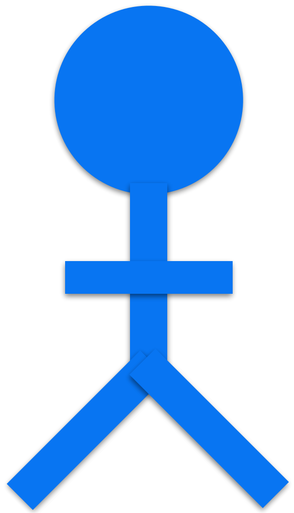

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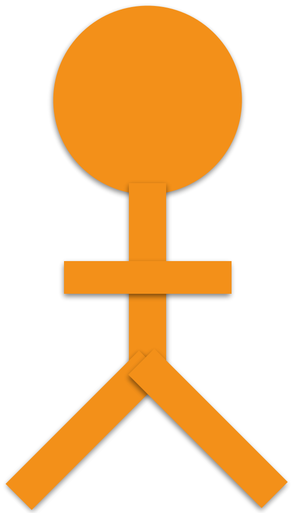

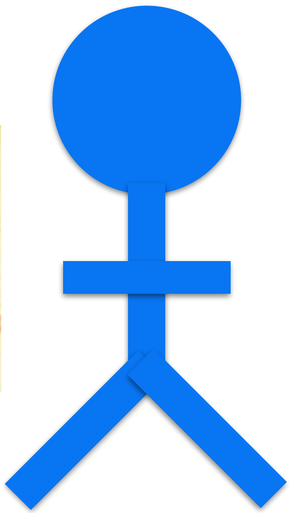

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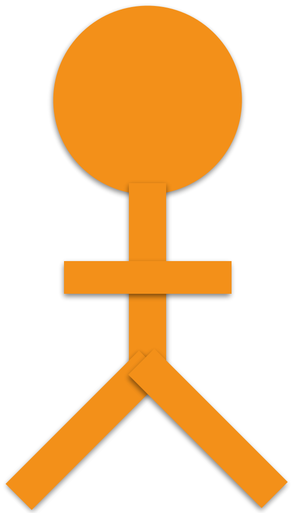

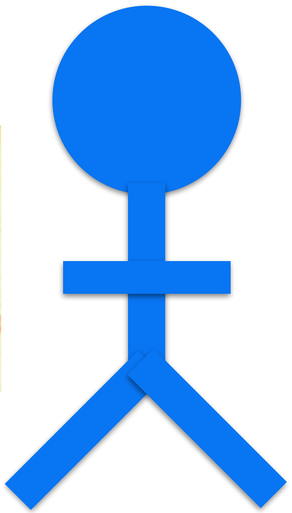

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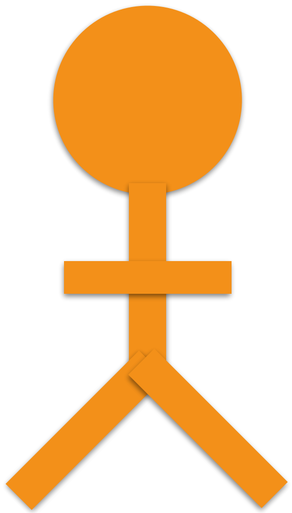

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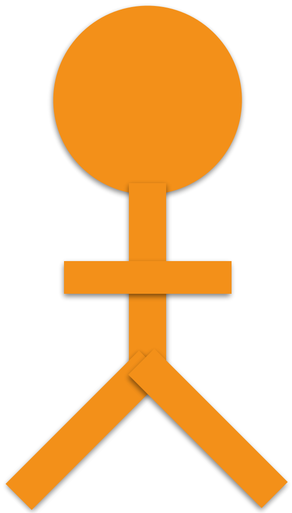

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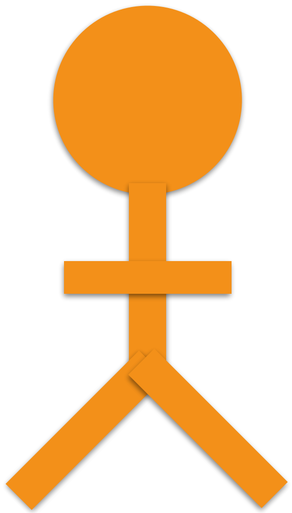

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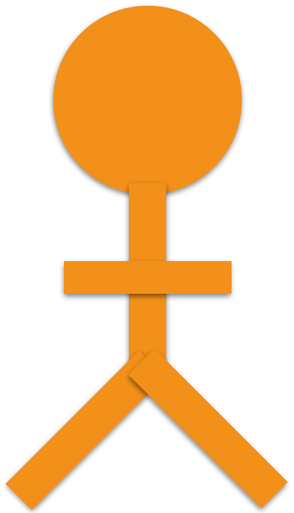
```

Error: use of moved value: `name`



Ownership

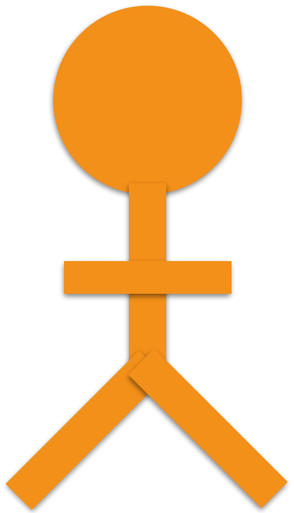
```
void main() {
  Vector name = …;
  helper(name);
  helper(name);
}
```

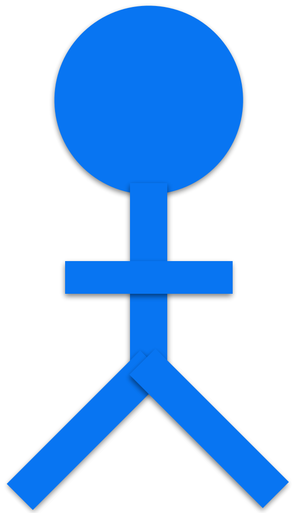
```
void helper(Vector name) {
  …
}
```

“Ownership” in Java

```
void main() {
  Vector name = …;
  helper(name);
  helper(name);
}
```

```
void helper(Vector name) {
  …
}
```



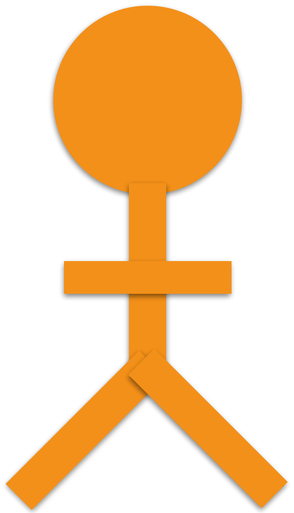


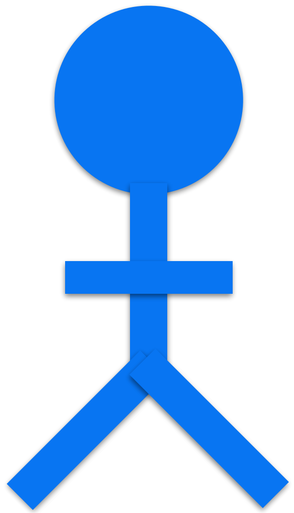
“Ownership” in Java

```
void main() {
  Vector name = …;
  helper(name);
  helper(name);
}
```

```
void helper(Vector name) {
  …
}
```

Take **reference** to Vector

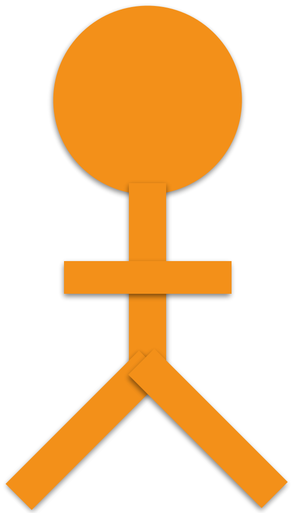


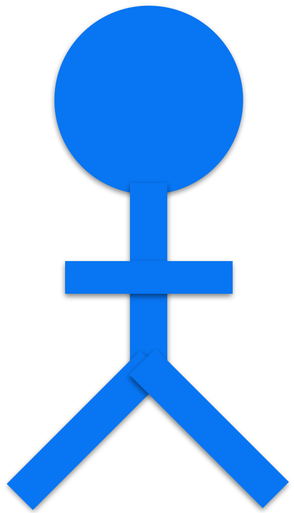


“Ownership” in Java

```
void main() {
  Vector name = …;
  helper(name);
  helper(name);
}
```

```
void helper(Vector name) {
  …
}
```





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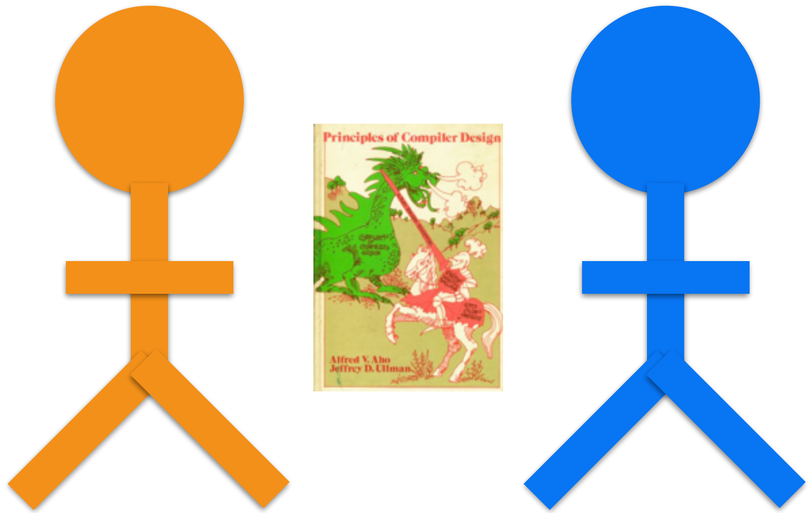

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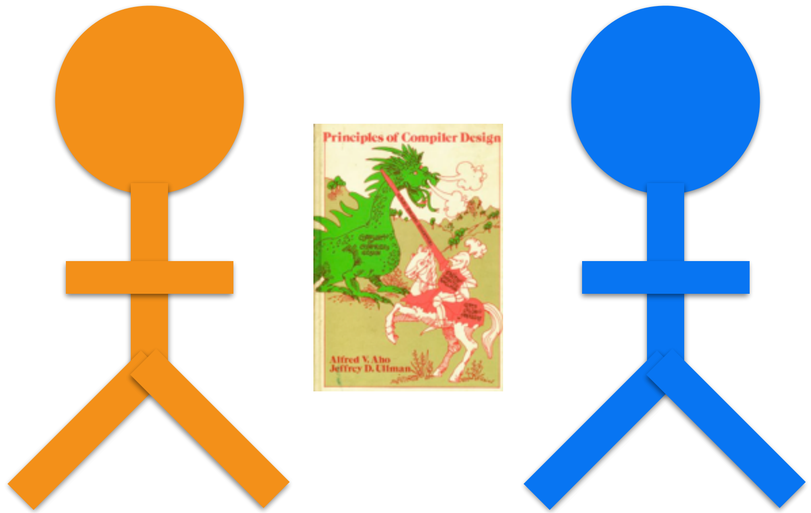

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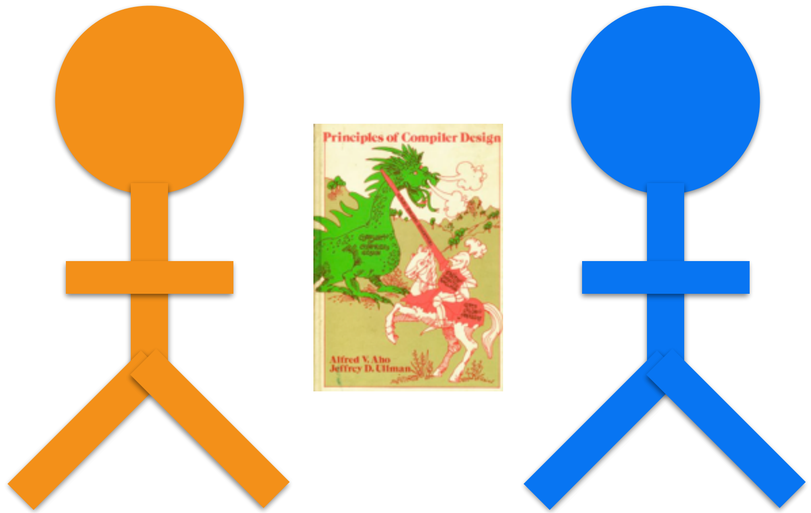

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“Ownership” in Java

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void helper(Vector name) {
  …
}
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“Ownership” in Java

```
void main() {
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}
```

```
void helper(Vector name) {
  new Thread(…);
}
```

“Ownership” in Java

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void main() {
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  helper(name);
}
```

```
void helper(Vector name) {
  new Thread(…);
}
```

“Ownership” in Java

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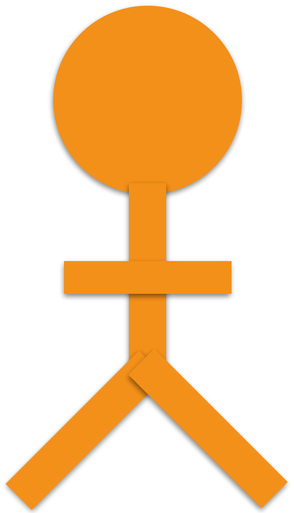
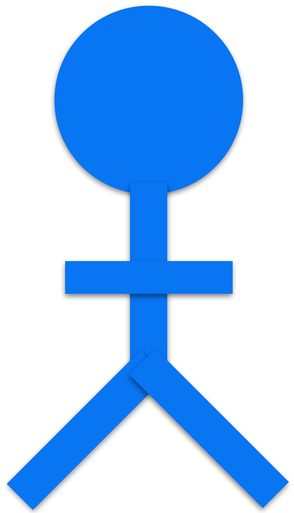
“Ownership” in Java

Clone

```
fn main() {
  let name = format!("…");
  helper(name.clone());
  helper(name);
}
```

```
fn helper(name: String) {
  println!(..);
}
```





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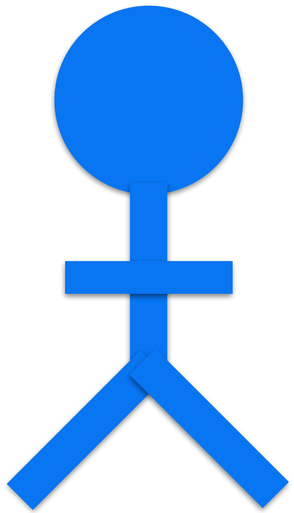

Clone

```
fn main() {
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  helper(name);
}
```

Copy the String

```
fn helper(name: String) {
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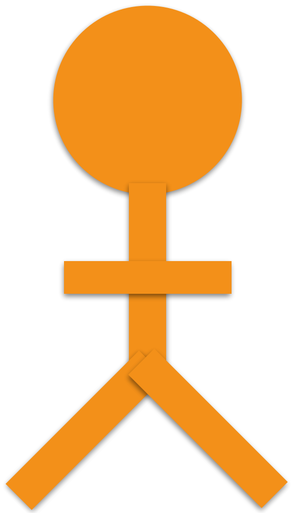
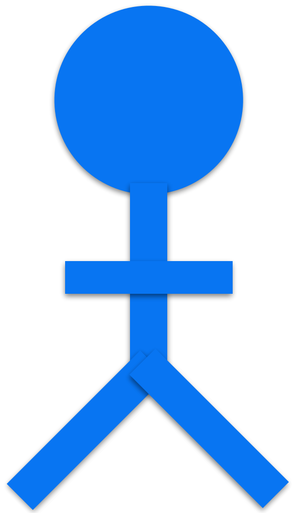
}
```





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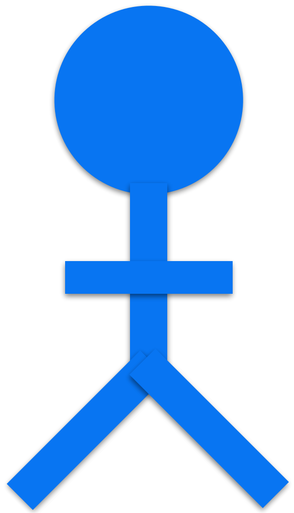

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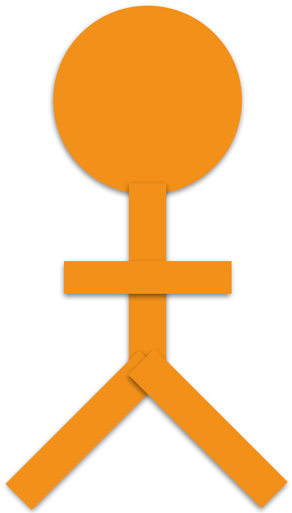

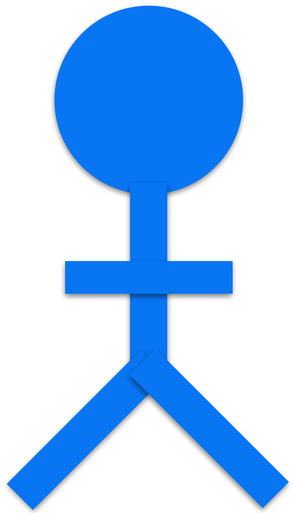

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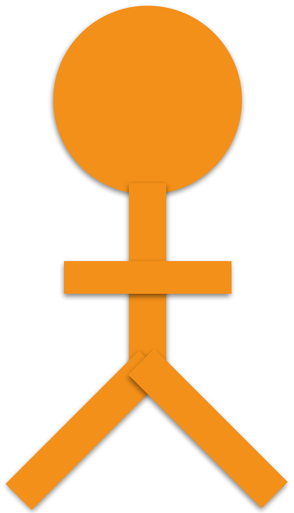

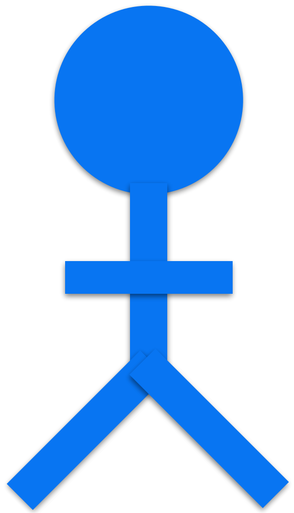

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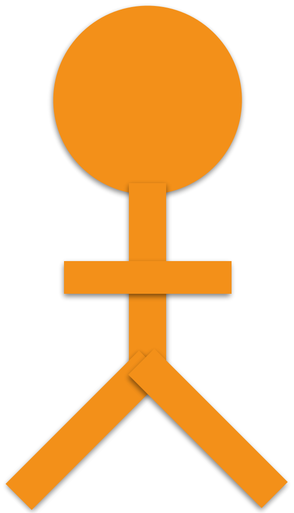
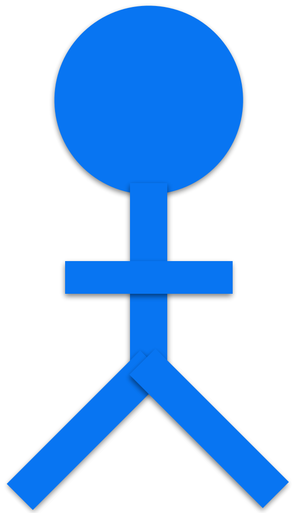
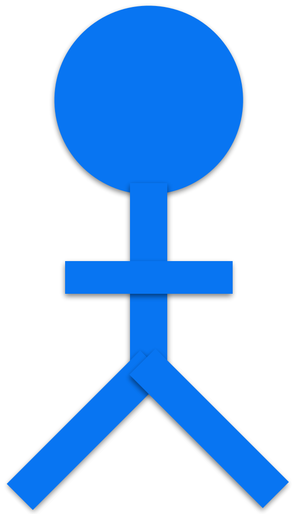




Copy (auto-Clone)

```
fn main() {
    let count = 22;
    helper(count);
    helper(count);
}
```

```
fn helper(count: i32) {
    println!(..);
}
```



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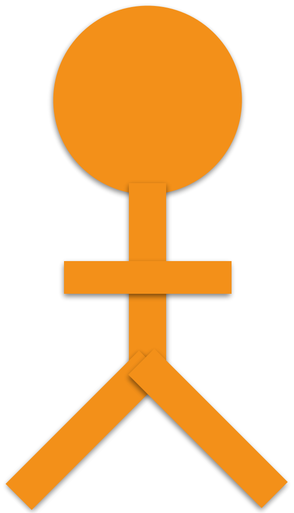
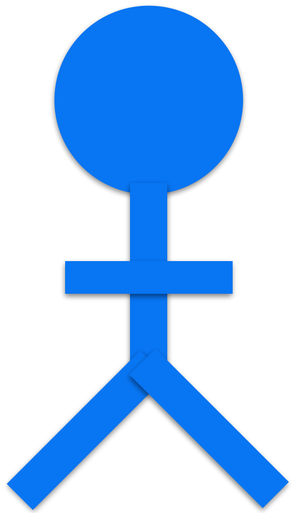
i32 is a Copy type





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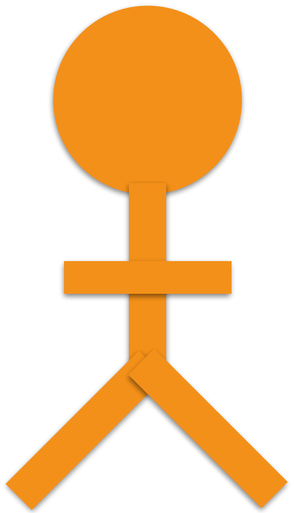

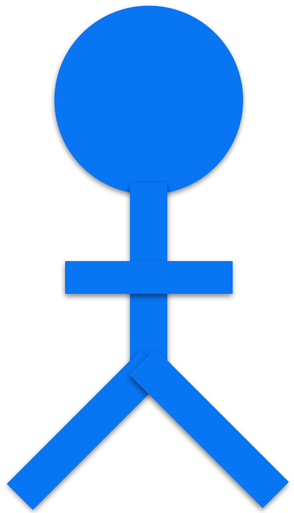

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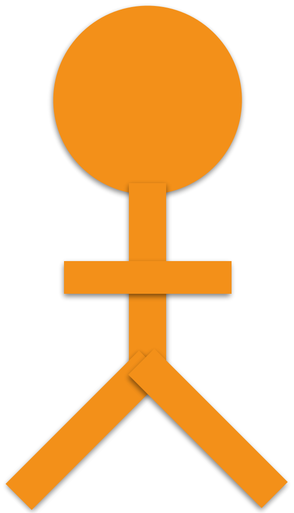

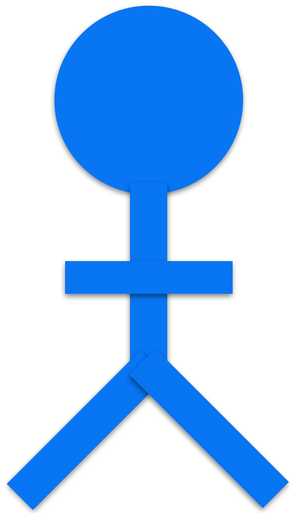

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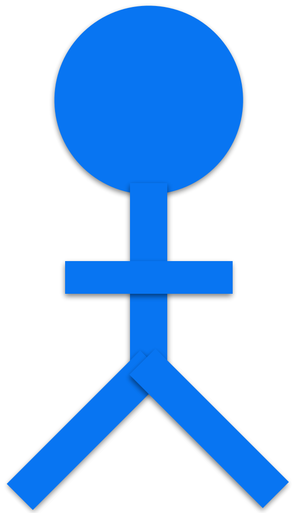


Non-copyable: Values **move** from place to place.

Example: *money*

Clone: Run custom code to make a copy.

Example: *strings*

Copy: Type is implicitly copied when referenced.

Example: *integers or floating-point numbers*

Exercise: **ownership**

http://rust-tutorials.com/exercises/

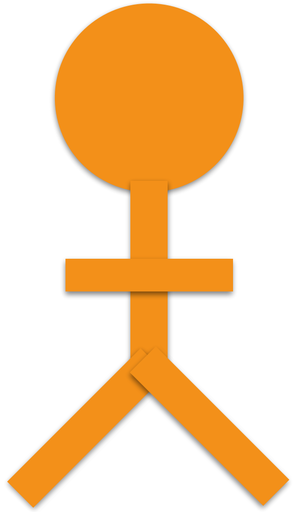
Cheat sheet:

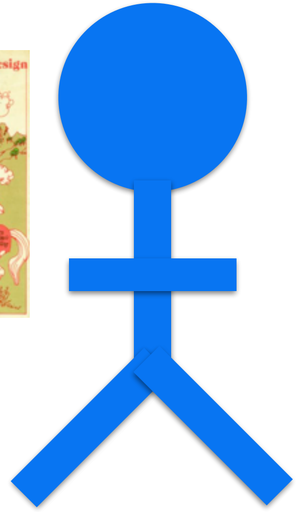
```
fn helper(name: String) // takes ownership

string.clone()          // clone the string
```

http://doc.rust-lang.org/std

Borrowing: Shared Borrows



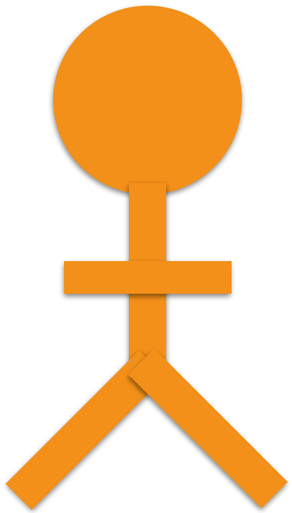


Borrowing: Shared Borrows

Borrowing: Shared Borrows

```
fn main() {
  let name = format!("…");
  let reference = &name;
  helper(reference);
  helper(reference);
}
```

```
fn helper(name: &String) {
  println!(..);
}
```



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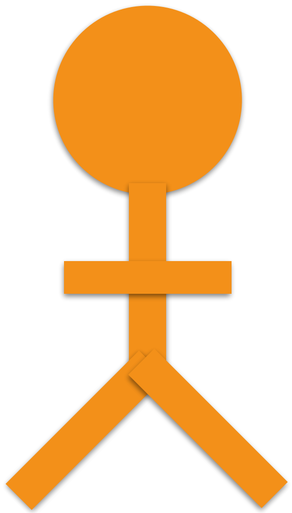

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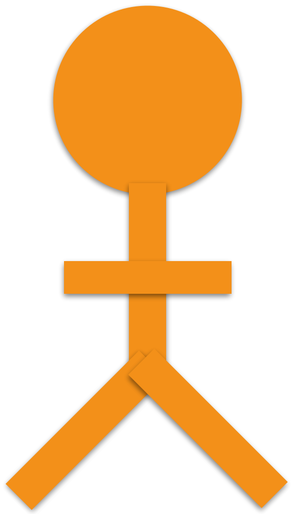
Change type to a **reference** to a String



Shared borrow

```rust
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    helper(reference);
}
```

```rust
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```

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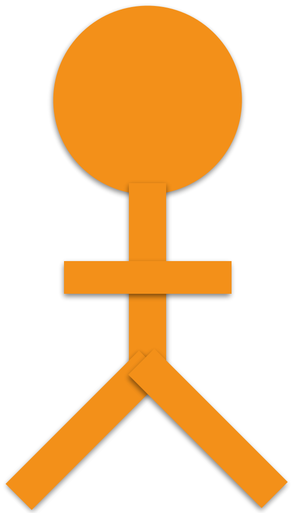

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Lend the string, creating a reference

```
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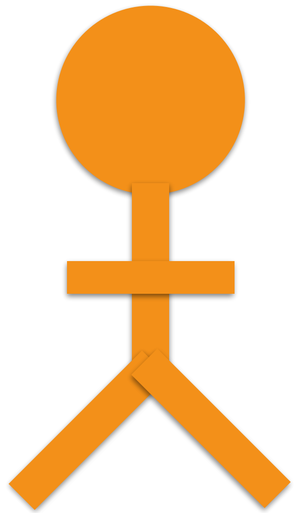

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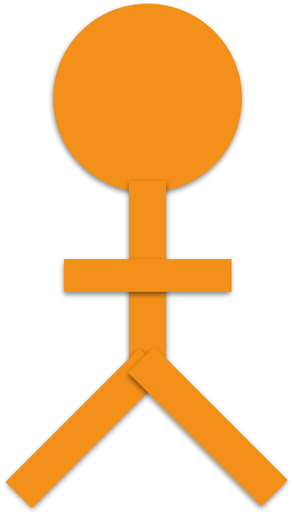

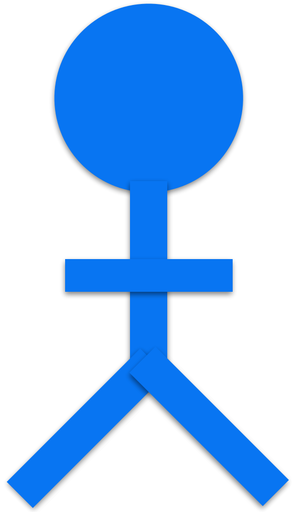

Shared borrow

```
fn main() {
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    helper(reference);
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Lend the string, creating a reference

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fn helper(name: &String) {
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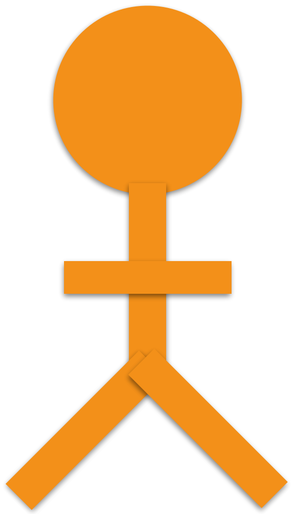

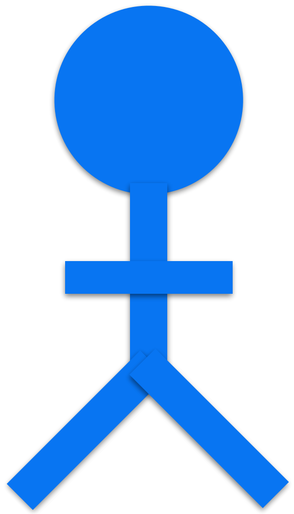

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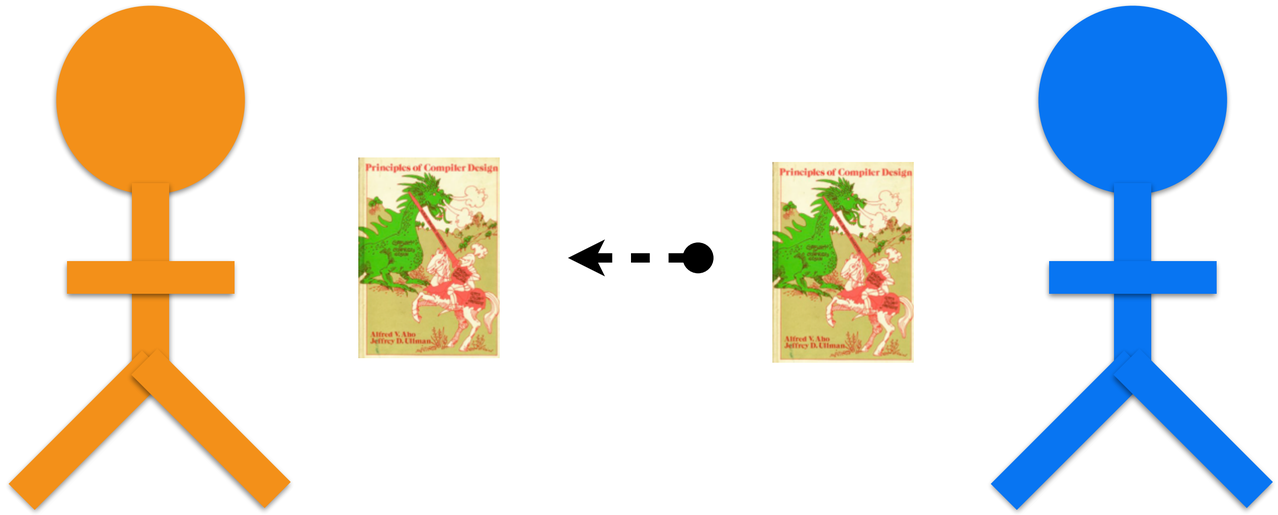

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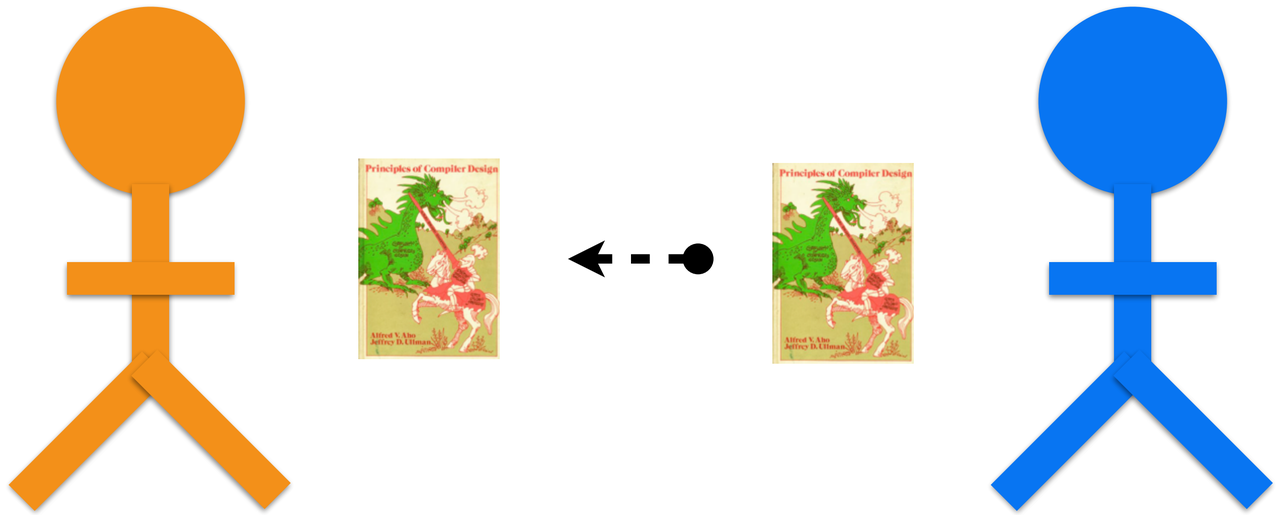

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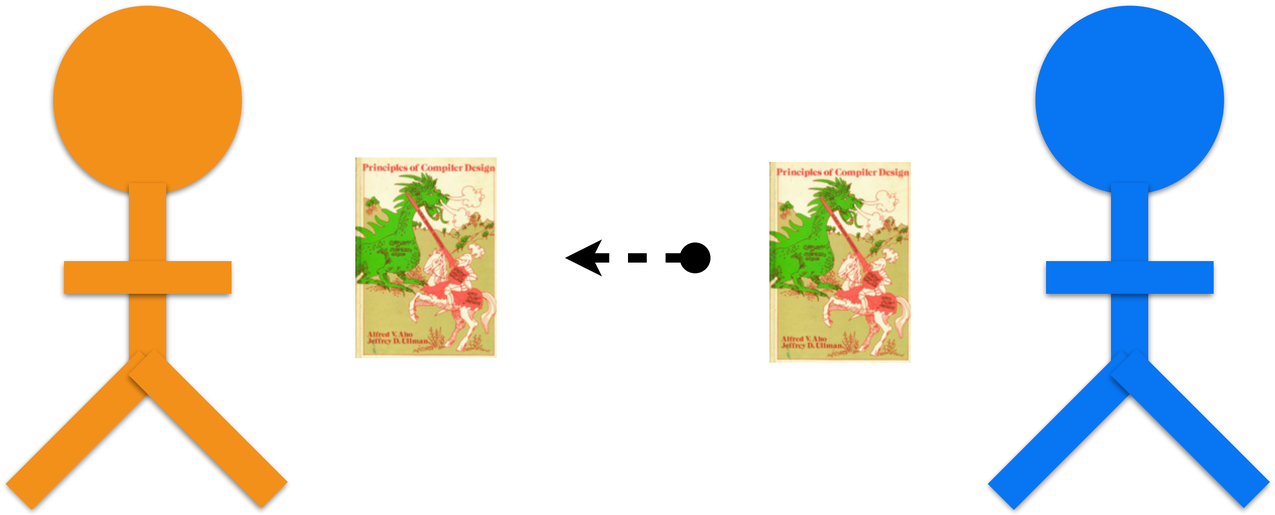

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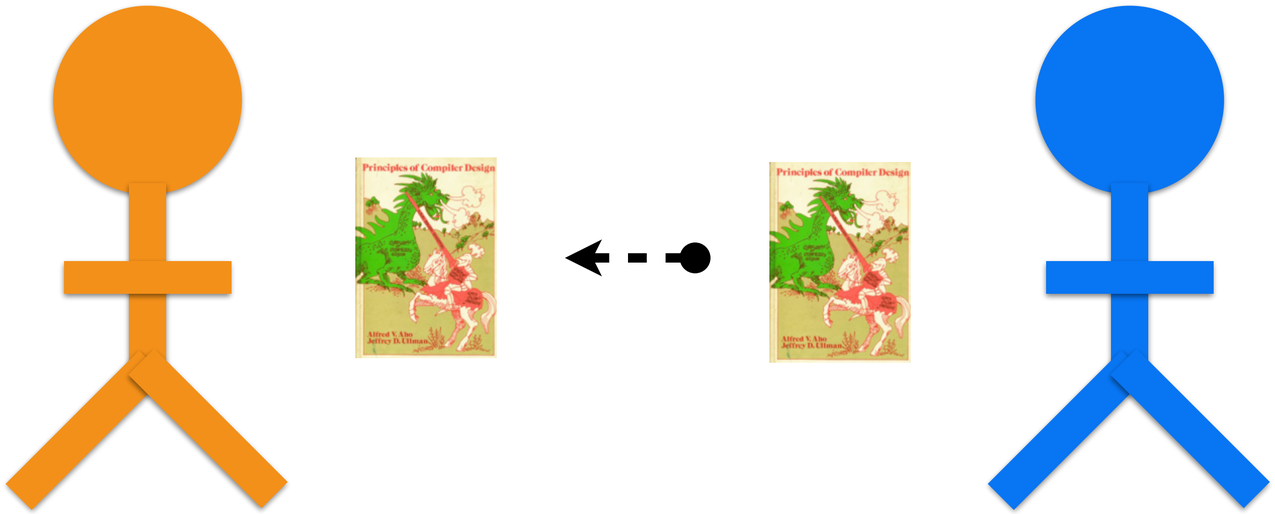

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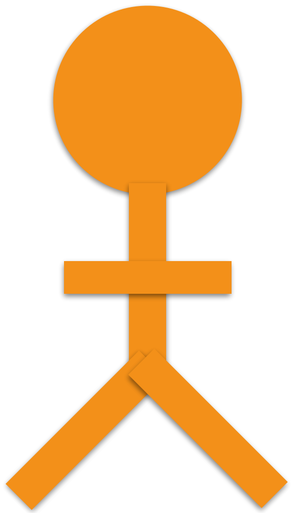

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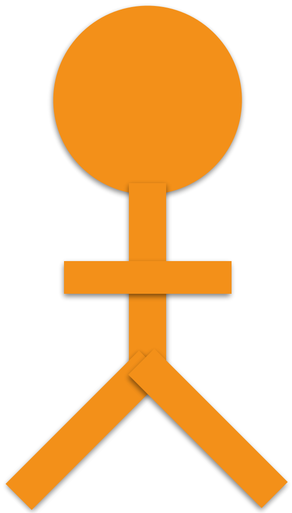

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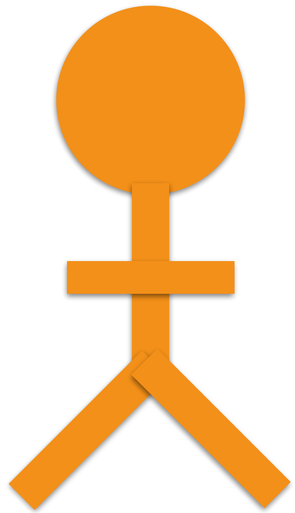

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```
fn helper(name: &String) {
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}
```

Shared borrow

Shared == Immutable

```
fn helper(name: &String) {
  println!(“{}”, name);
}

fn helper(name: &String) {
  name.push_str(“foo”);
}
```

Shared == Immutable

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fn helper(name: &String) {
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OK. Just reads.

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fn helper(name: &String) {
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Error. Writes.

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error: cannot borrow immutable borrowed content `*name`
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    name.push_str(“s”);
    ^~~~
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Shared == Immutable*

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error: cannot borrow immutable borrowed content `*name`
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    name.push_str(“s”);
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```

* **Actually:** mutation only in **controlled circumstances**.

Play time

Waterloo, Cassius Coolidge, c. 1906

http://is.gd/no0tTH

```
fn main() {
  let name = format!("…");
  helper(&name[1..]);
  helper(&name);
}
```

```
fn helper(name: &str) {
  println!(..);
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```

Looks like other languages:

- Python: name[1:]
- Ruby: name[1..-1]

But no copying at runtime.

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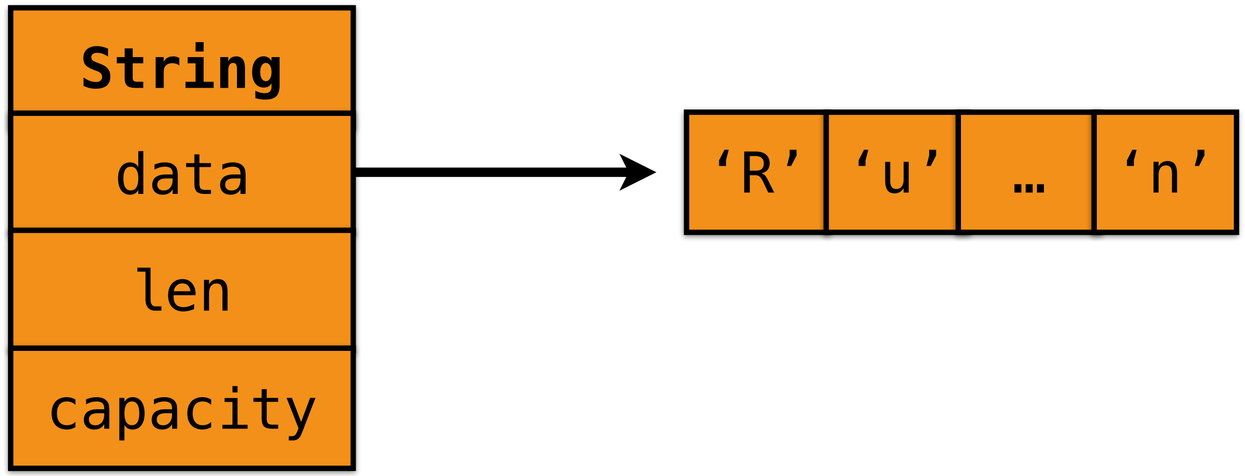

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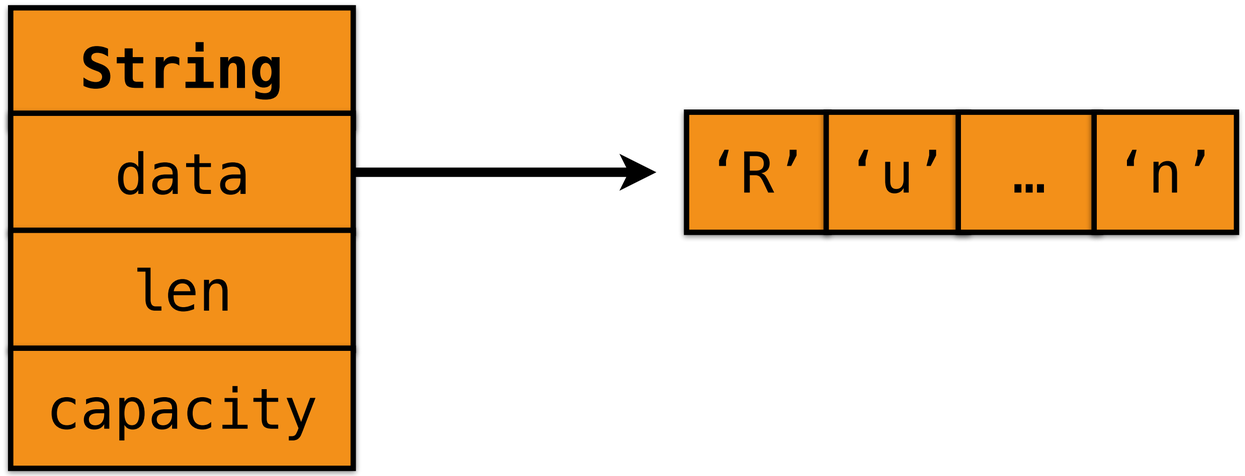

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Change type from `&String`
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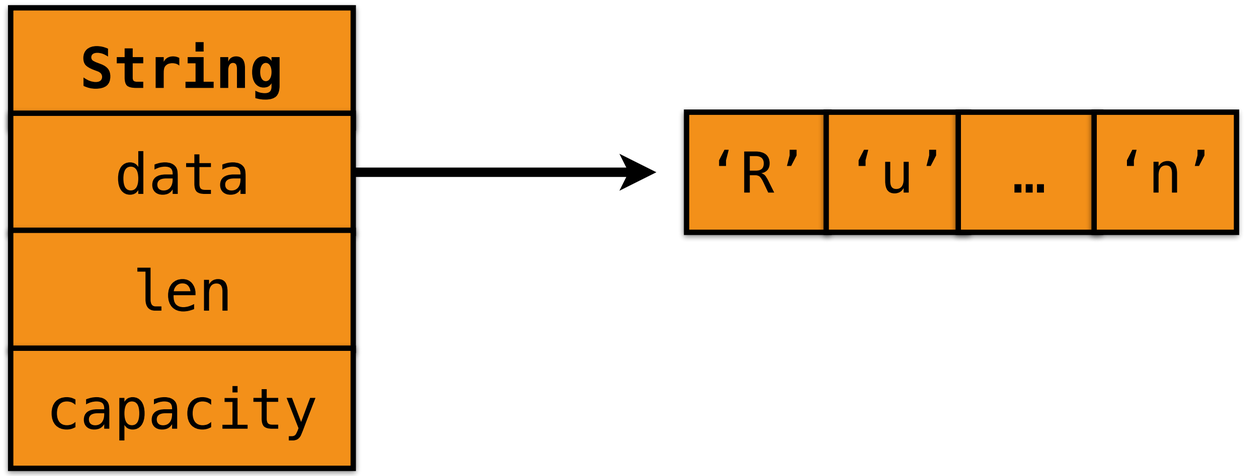

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Lend some of the string

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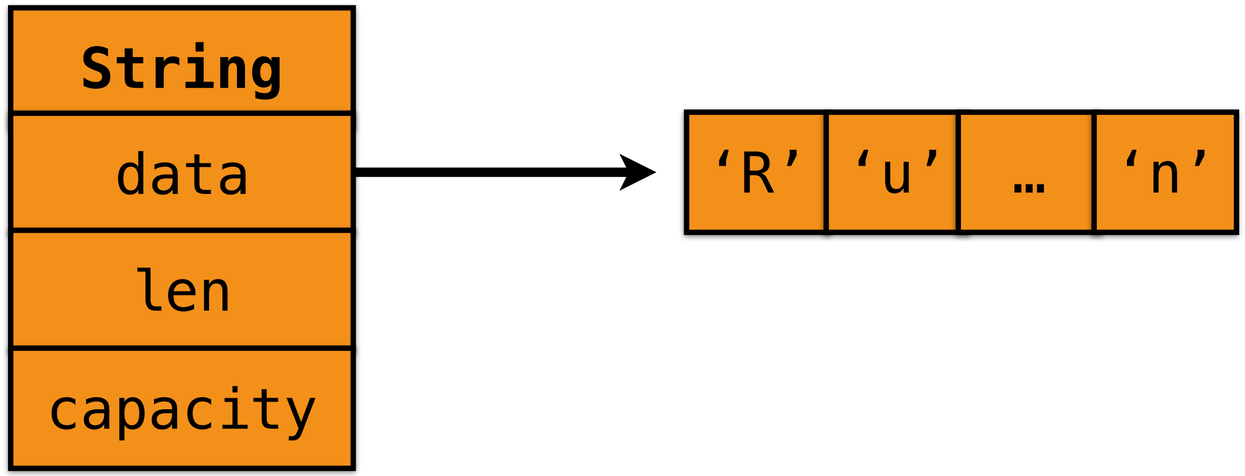

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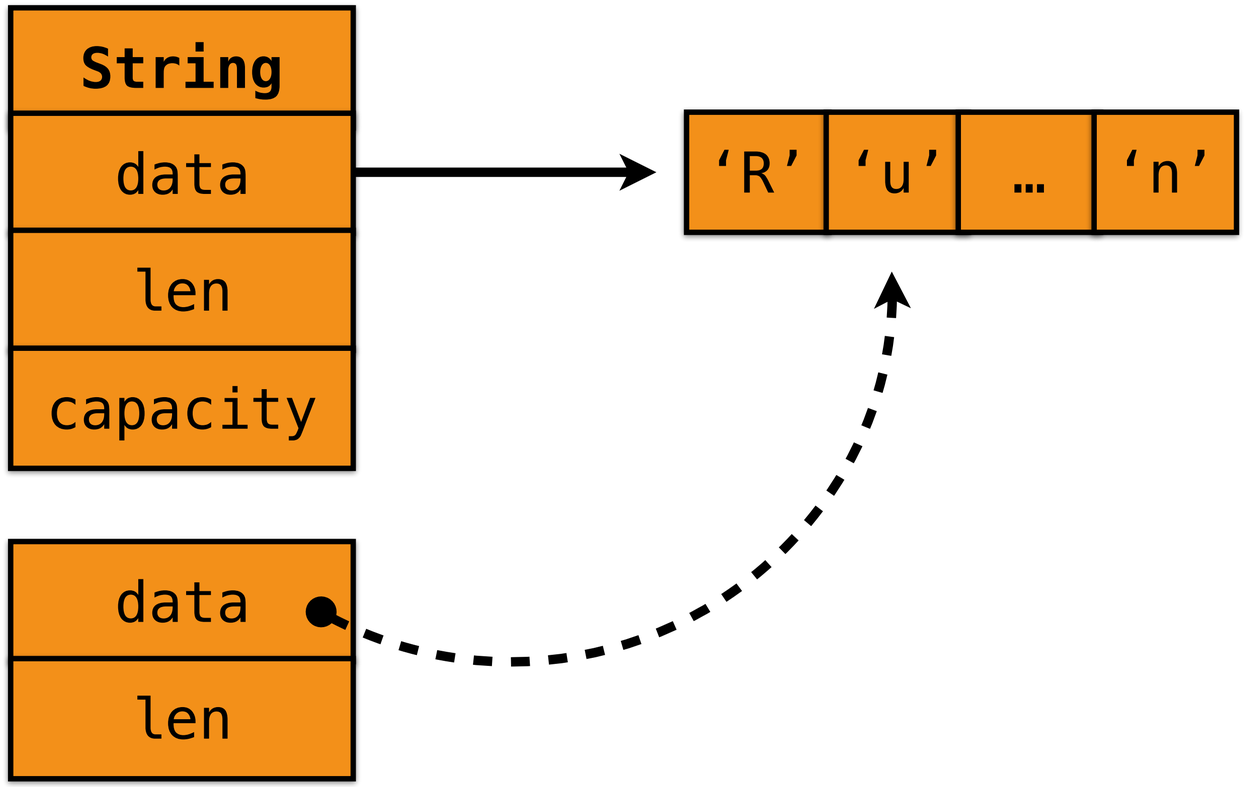

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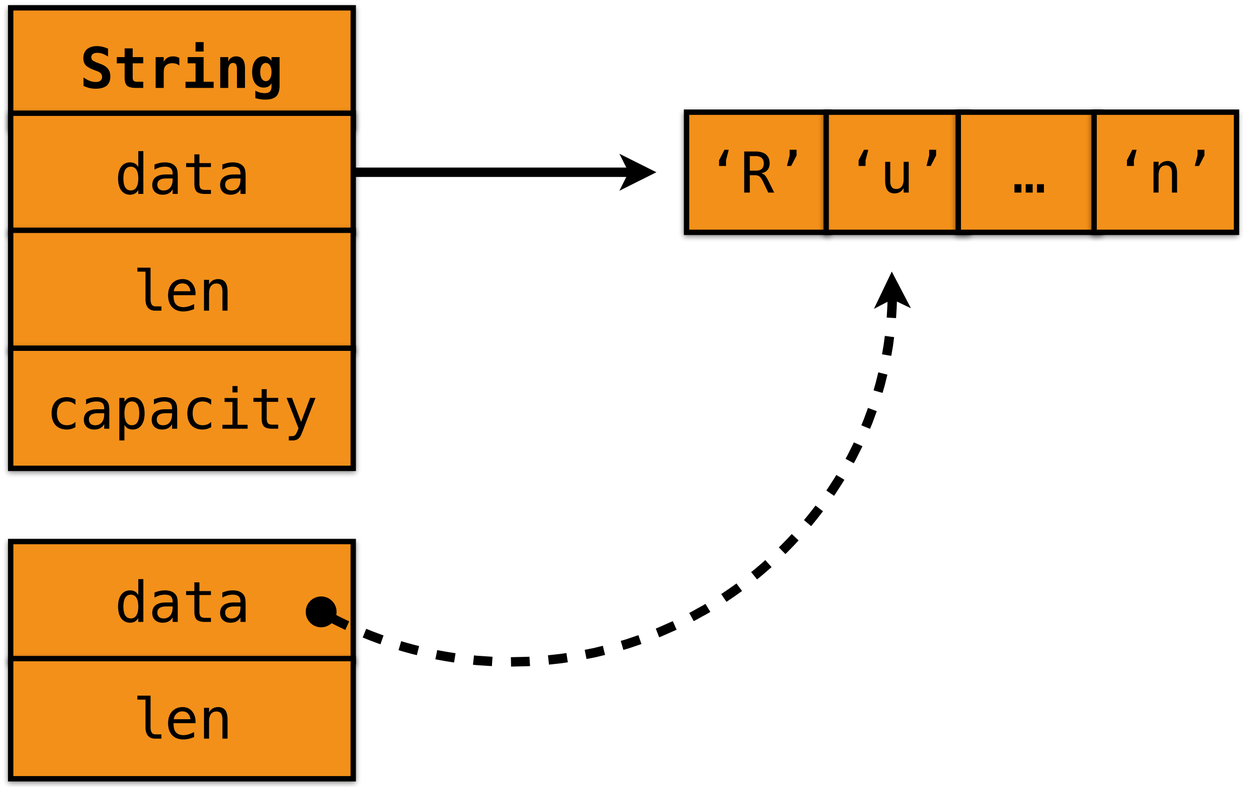

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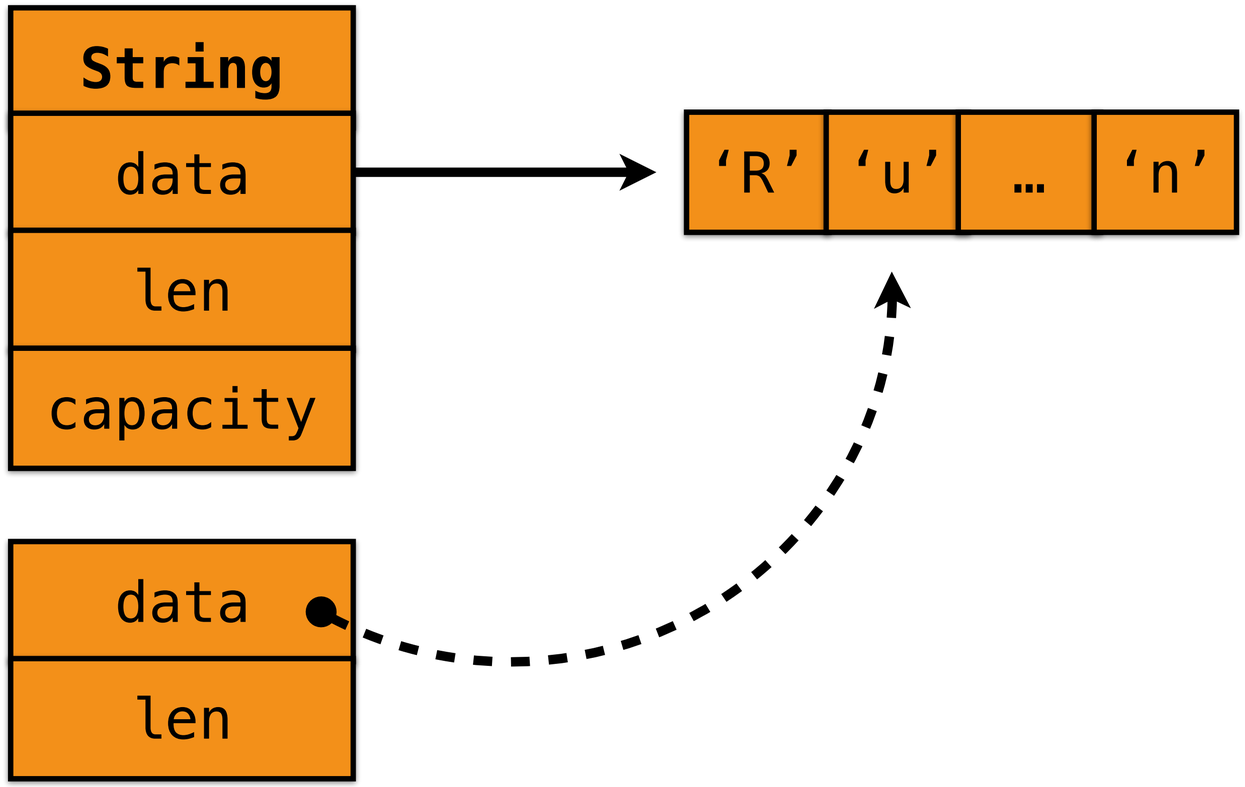

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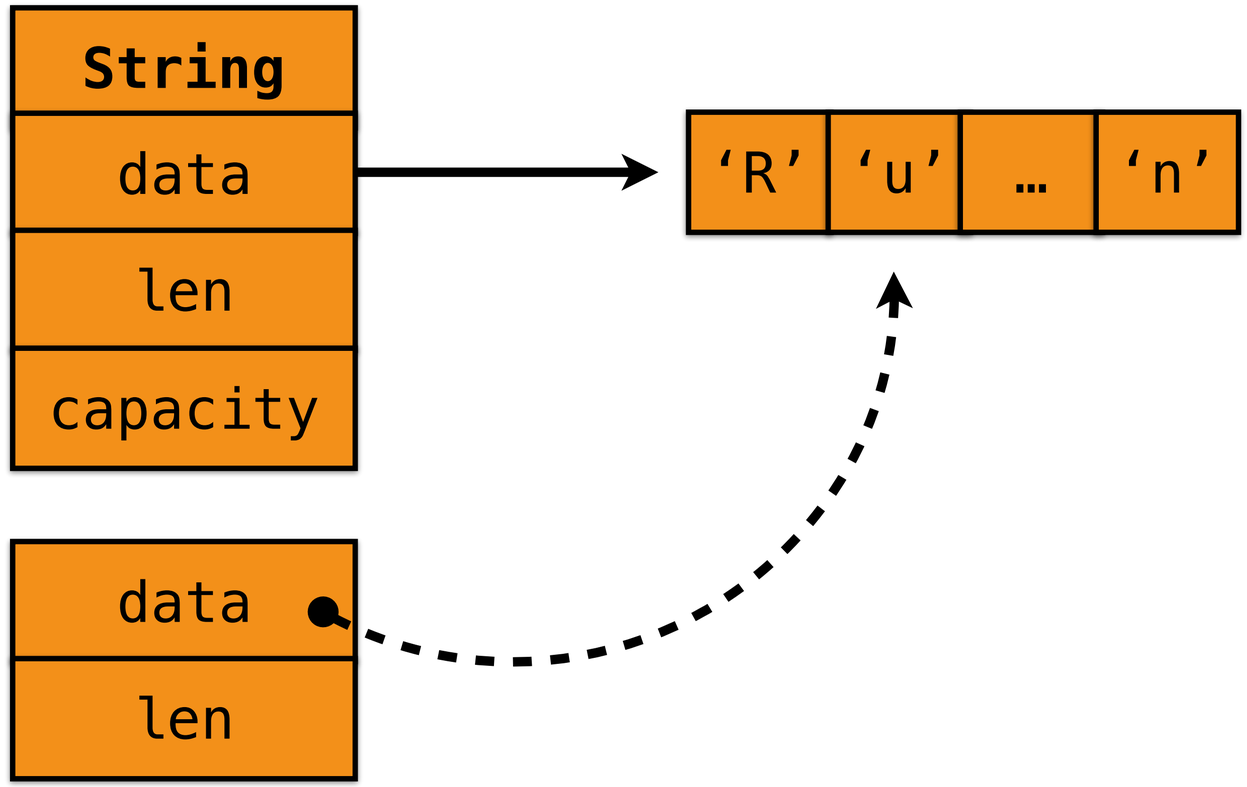

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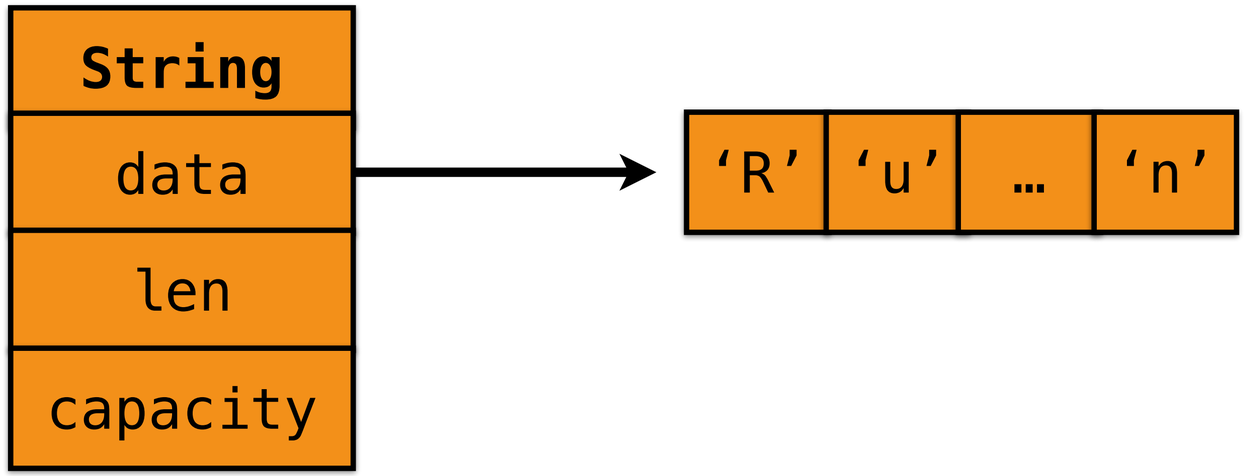

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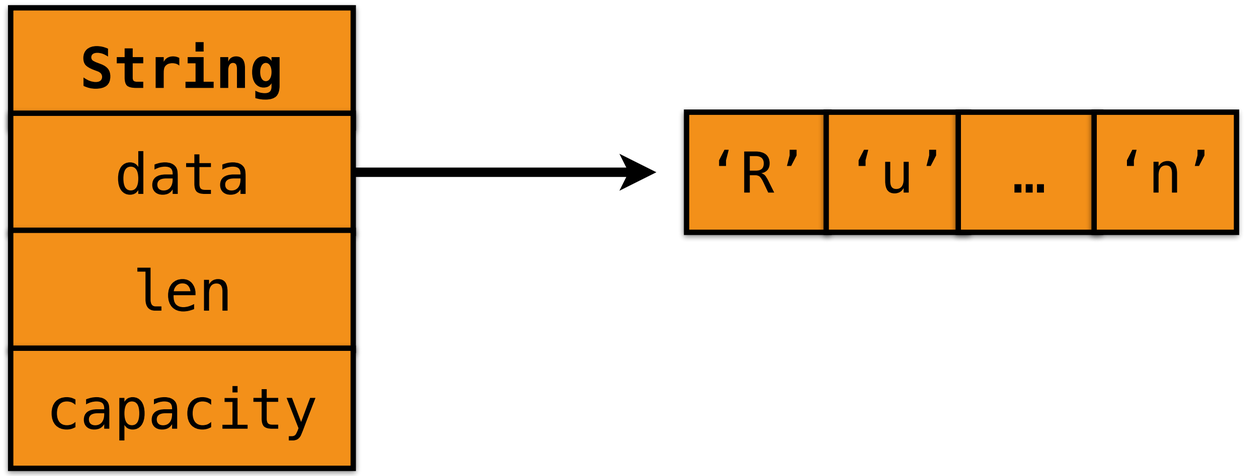

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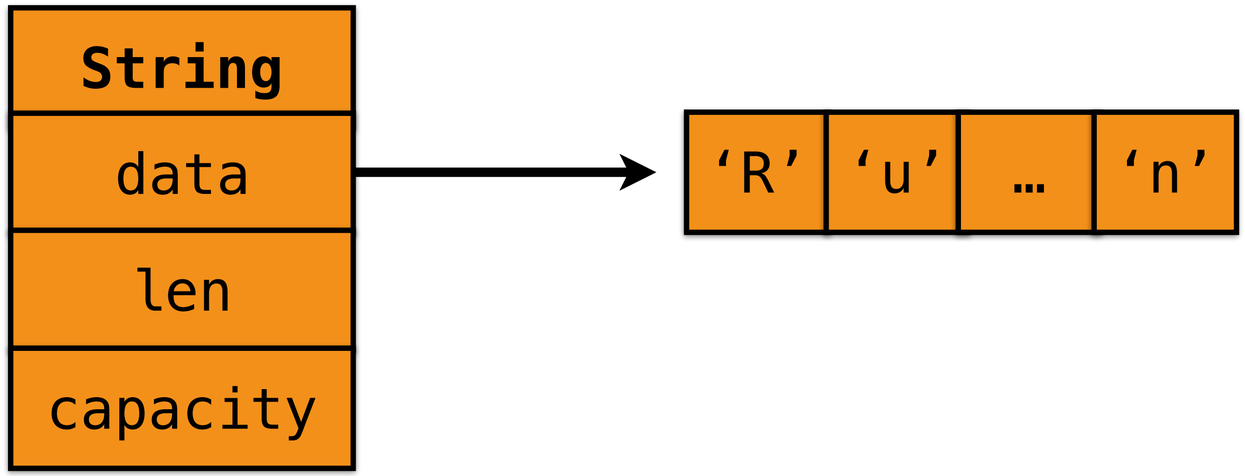

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High-level code, low-level efficiency

```
for word in line.split(' ') {
    sum += word.len();
}
```

No copying, no allocations.

High-level code, low-level efficiency

```
for word in line.split(' ') {
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Iterator over slices borrowed from **line**.

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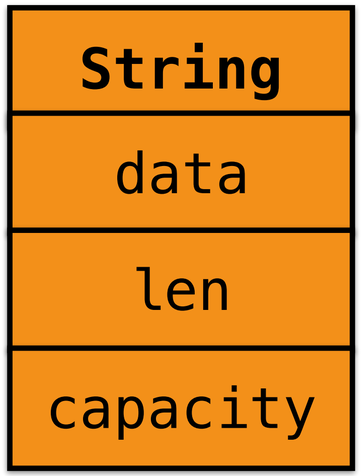

“Sing, Goddess, of Achilles’ rage, black and murderous…

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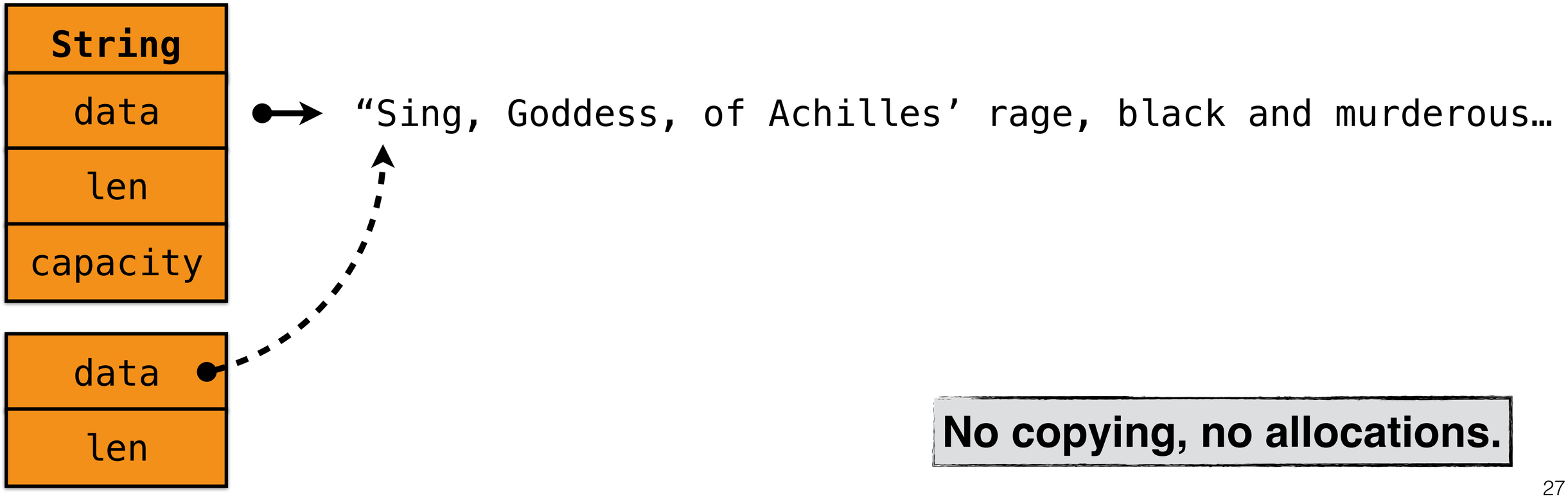

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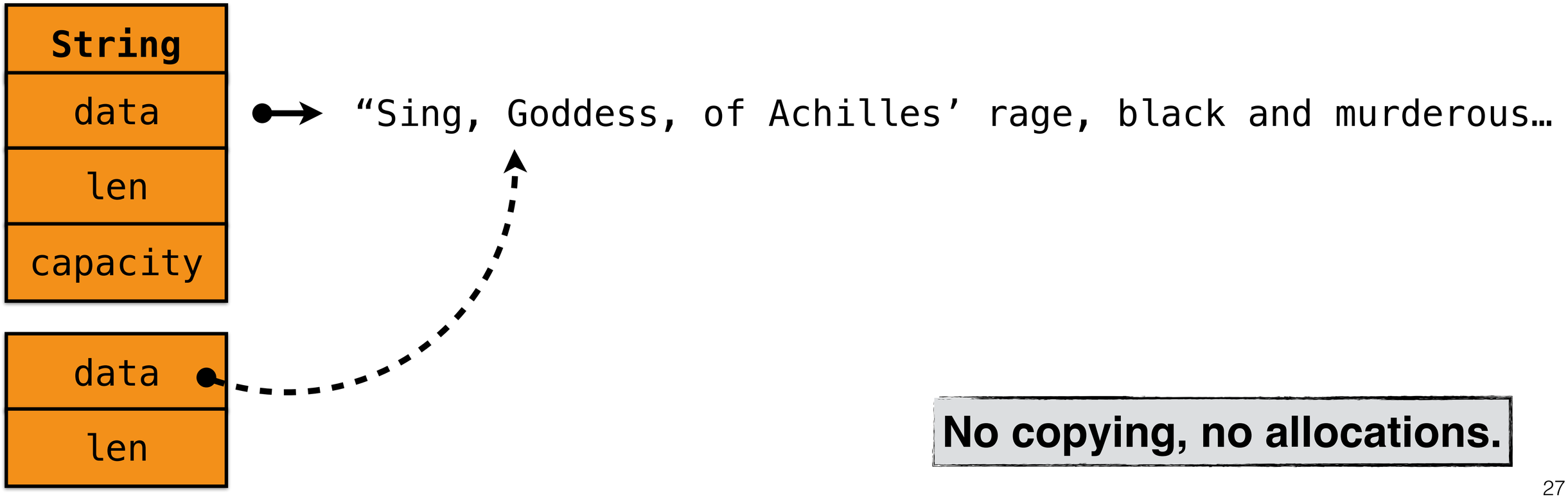

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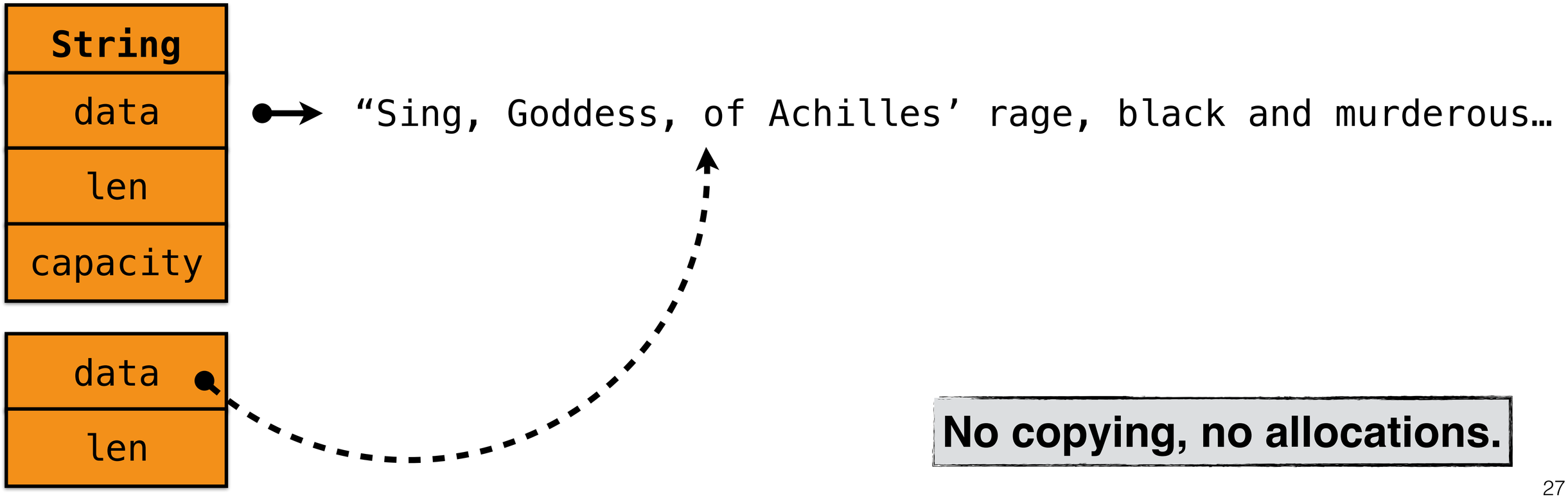


No copying, no allocations.

Exercise: **shared borrow**

http://rust-tutorials.com/exercises/

Cheat sheet:

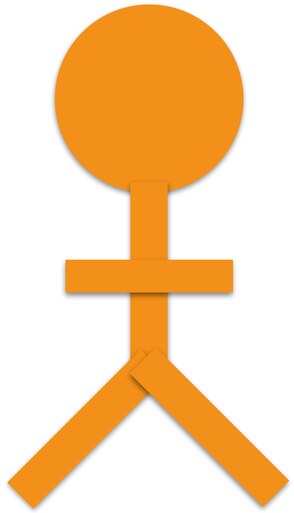
```
&String          // type of shared reference
&str             // type of string slice

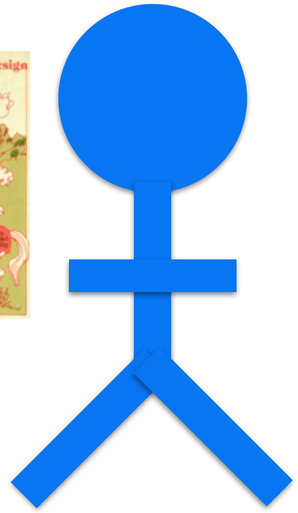
fn greet(name: &String) {..}

&name            // shared borrow
&name[x..y]      // slice expression
```

http://doc.rust-lang.org/std

Borrowing: Mutable Borrows



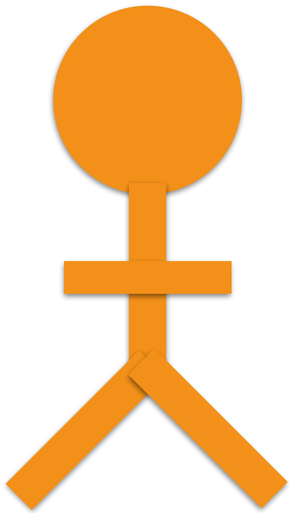


Borrowing: Mutable Borrows

Borrowing: Mutable Borrows

```
fn main() {
    let mut name = …;
    update(&mut name);
    println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
    name.push_str(“…”);
}
```



Mutable borrow

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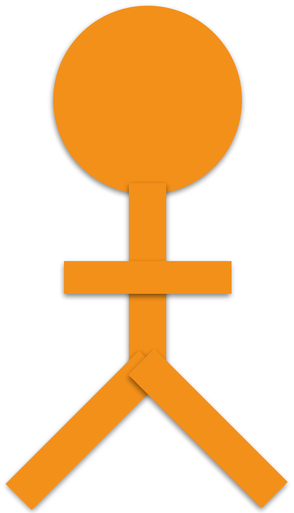

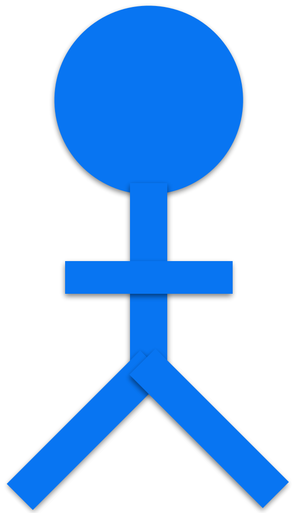

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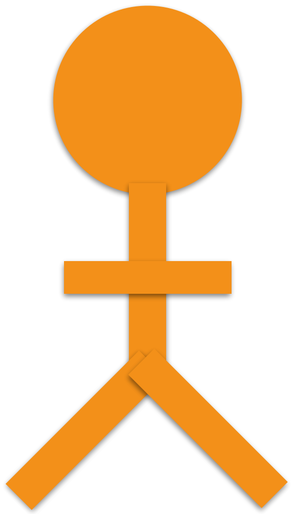
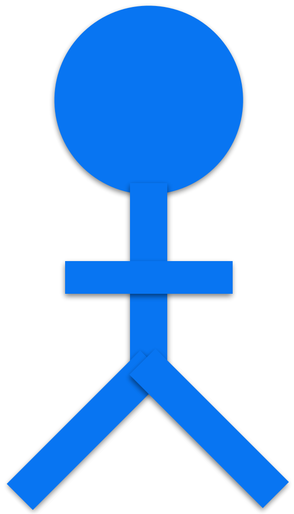
```

Take a **mutable reference** to a String





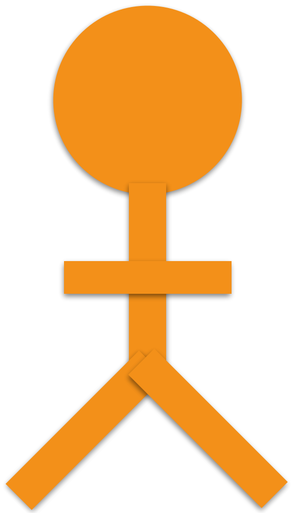
Mutable borrow

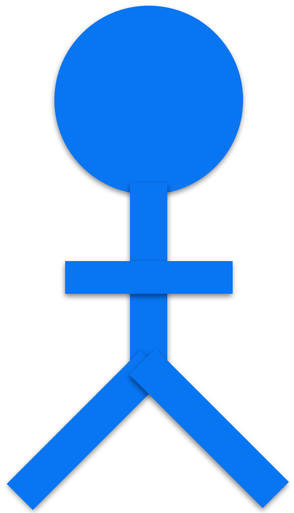
```
fn main() {
    let mut name = …;
    update(&mut name);
    println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
    name.push_str(“…”);
}
```

Take a **mutable reference** to a String

Lend the string **mutably**





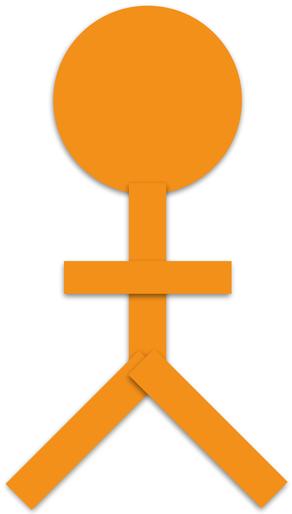
Mutable borrow

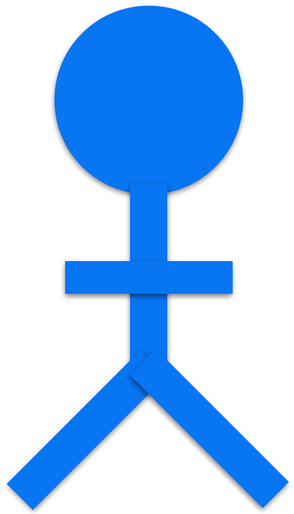
```
fn main() {
    let mut name = …;
    update(&mut name);
    println!(“{}”, name);
}
```

Lend the string **mutably**

```
fn update(name: &mut String) {
    name.push_str(“…”);
}
```

Take a **mutable reference** to a String





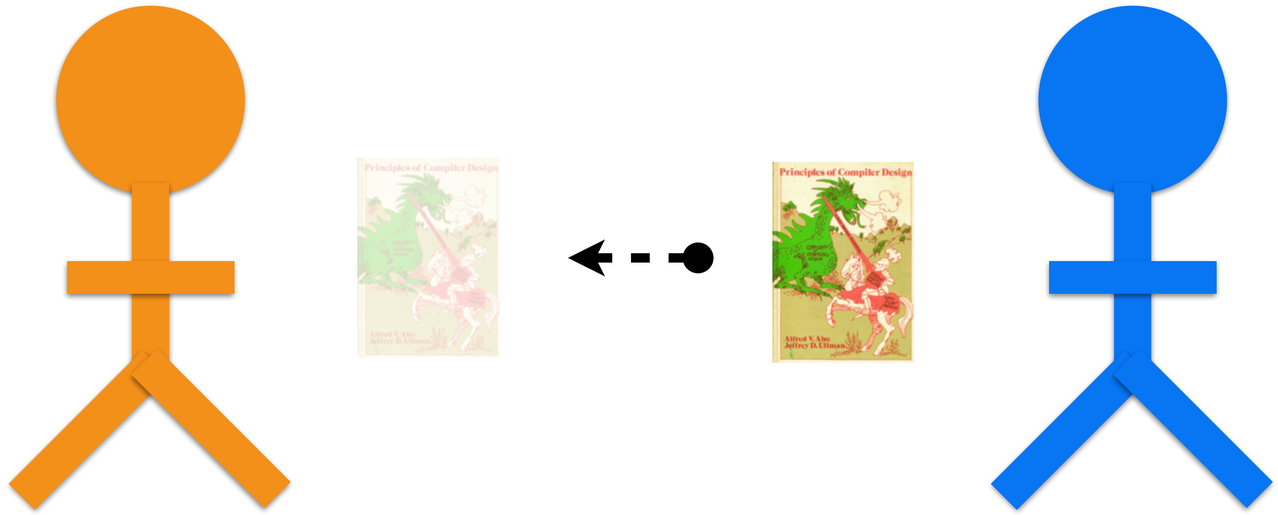
Mutable borrow

```
fn main() {
    let mut name = …;
    update(&mut name);
    println!(“{}”, name);
}
```

Lend the string **mutably**

```
fn update(name: &mut String) {
    name.push_str(“…”);
}
```

Take a **mutable reference** to a String



Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```

Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```

Mutable borrow

```rust
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

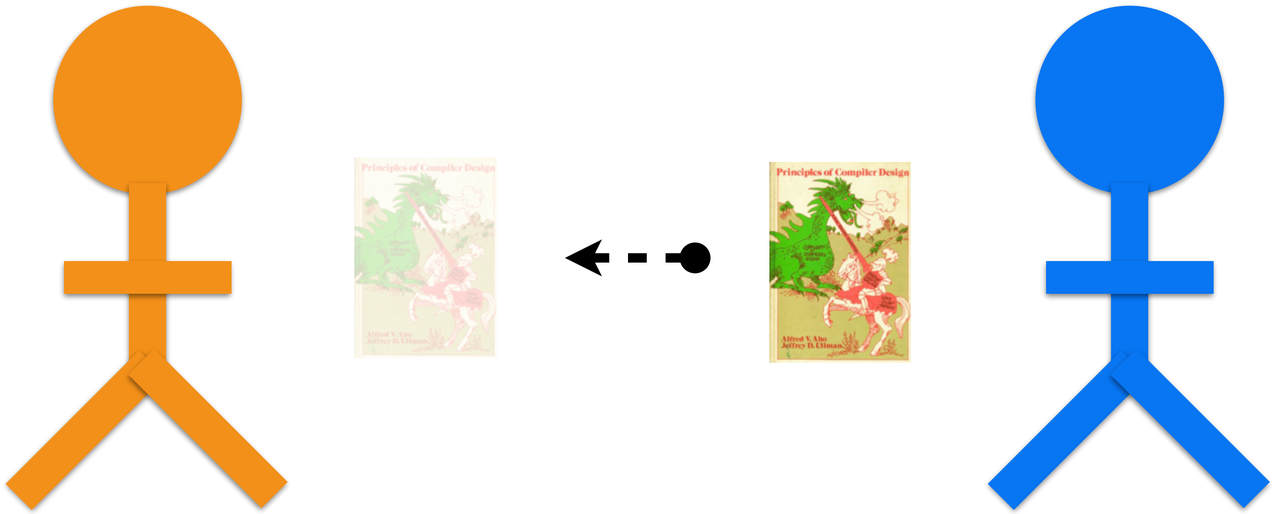
```rust
fn update(name: &mut String) {
  name.push_str(“…”);
}
```

Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```

Mutate string
in place



Mutable borrow

```rust
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

```rust
fn update(name: &mut String) {
  name.push_str(“…”);
}
```

Mutable borrow

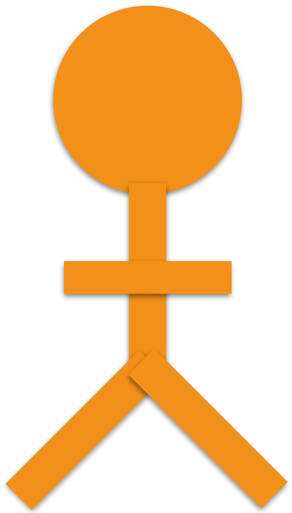
```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```

Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

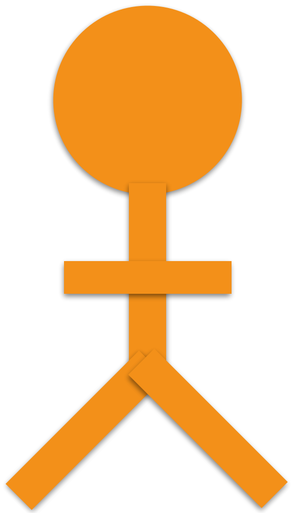
```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```



Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```



Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
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```

```
fn update(name: &mut String) {
  name.push_str(“…”);
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```
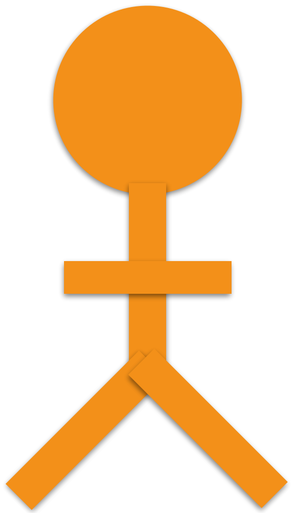
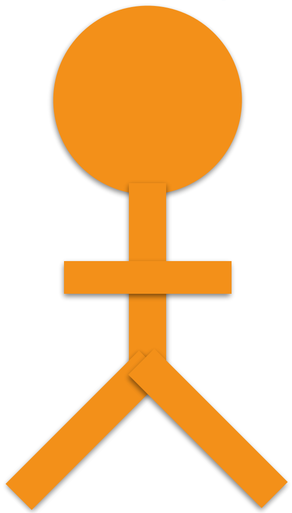



Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```

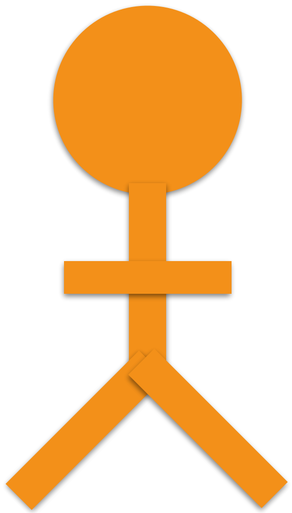
Prints the updated string.



Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

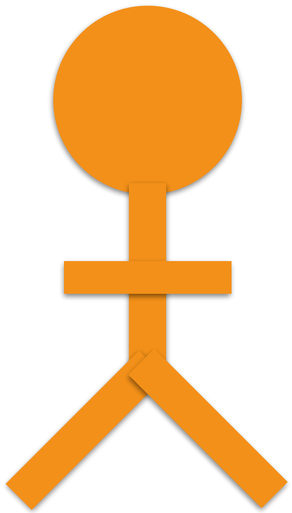
```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```



Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```



Mutable borrow

```
fn main() {
  let mut name = …;
  update(&mut name);
  println!(“{}”, name);
}
```

```
fn update(name: &mut String) {
  name.push_str(“…”);
}
```

Mutable borrow

```
name: String
```

Ownership:
control all access, will free when done

```
name: &String
```

Shared reference:
many readers, no writers

```
name: &mut String
```

Mutable reference:
no readers, one writer

```
name: String
```

Ownership:
control all access, will free when done

```
name: &String
```

Shared reference:
many readers, no writers

```
name: &mut String
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Mutable reference:
no readers, one writer

```
name: String
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Ownership:
control all access, will free when done

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name: &String
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Shared reference:
many readers, no writers

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Mutable reference:
no readers, one writer

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Ownership:
control all access, will free when done

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Shared reference:
many readers, no writers

```
name: &mut String
```

Mutable reference:
no readers, one writer

Play time

Waterloo, Cassius Coolidge, c. 1906

http://is.gd/no0tTH

How do we get safety?

https://www.flickr.com/photos/langtind/2217639550/in/photostream/

```
fn main() {
  let r;
  {
    let name = format!(“…”);
    r = &name;
  }
  println!(“{}”, r);
}
```

```
fn main() {
  let r;
  {
    let name = format!(“…”);
    r = &name;
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  println!(“{}”, r);
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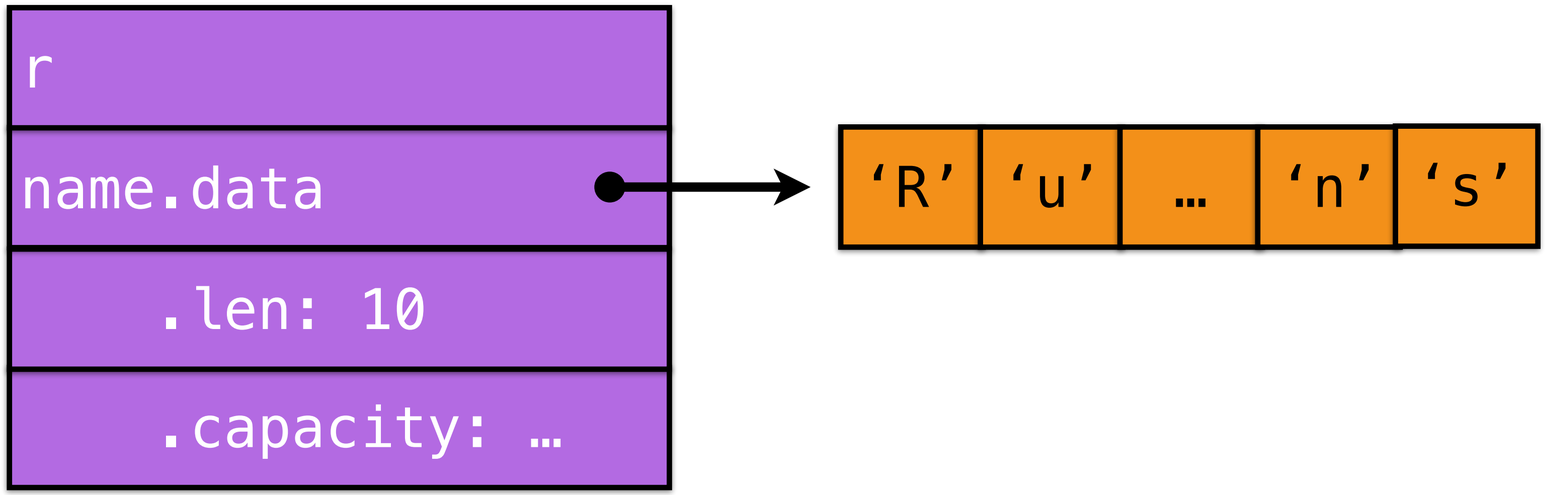

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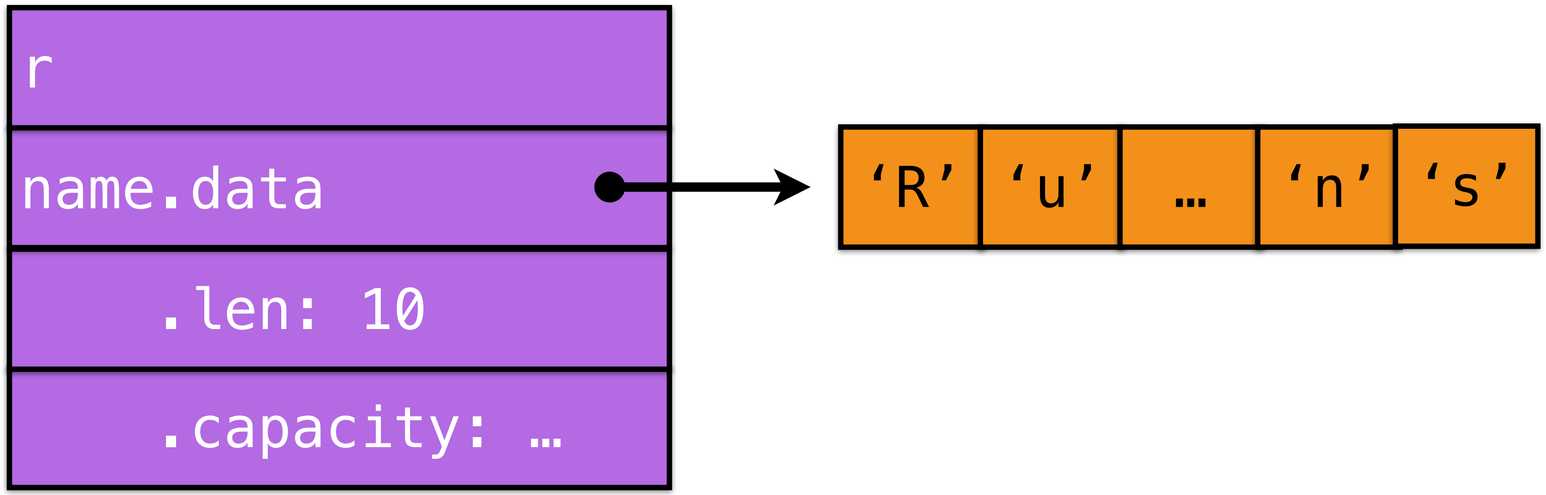

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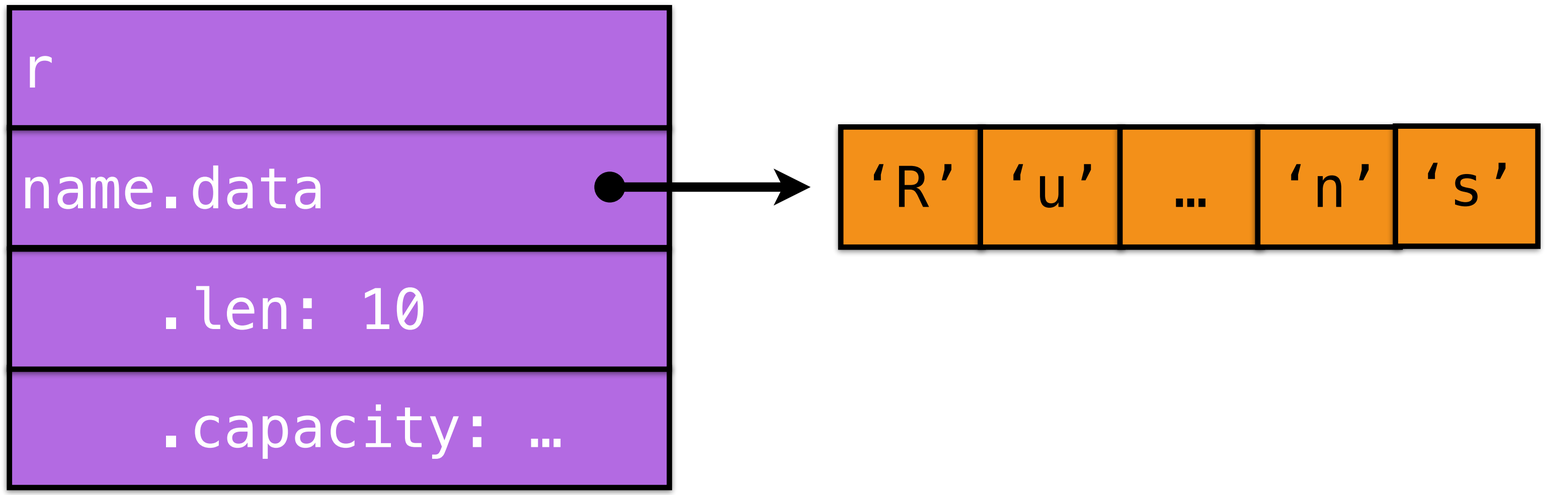

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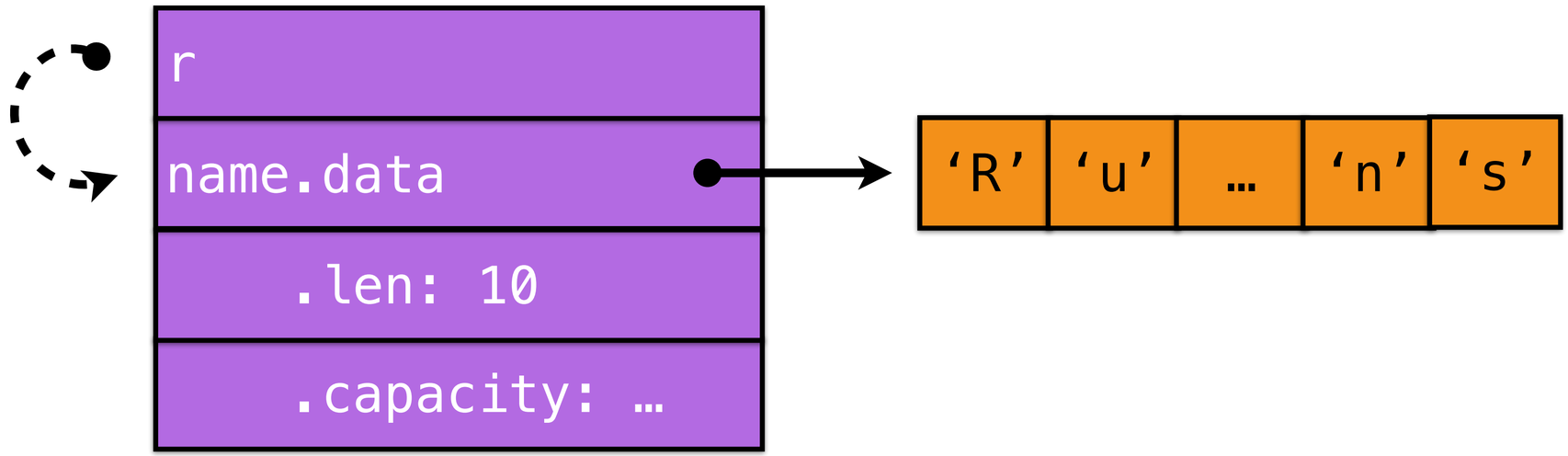

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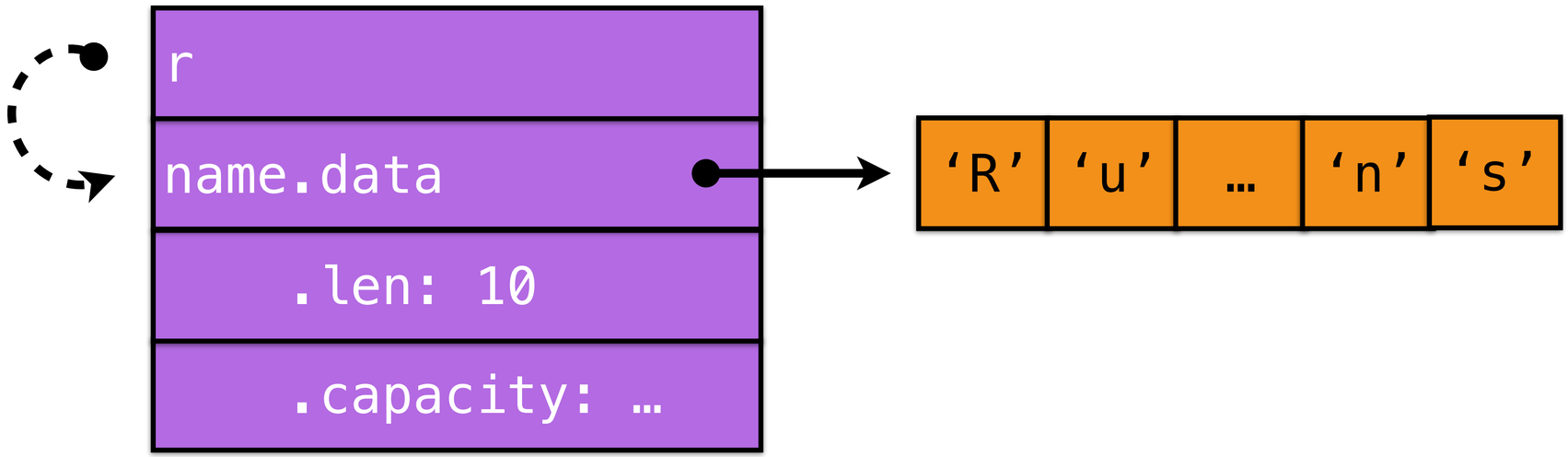

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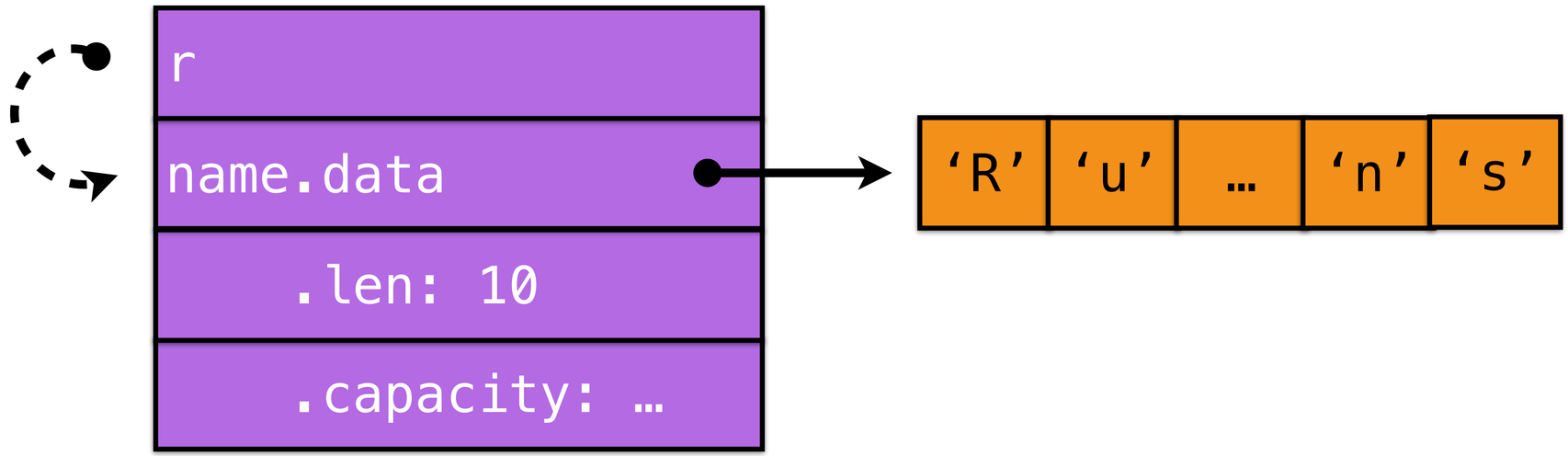

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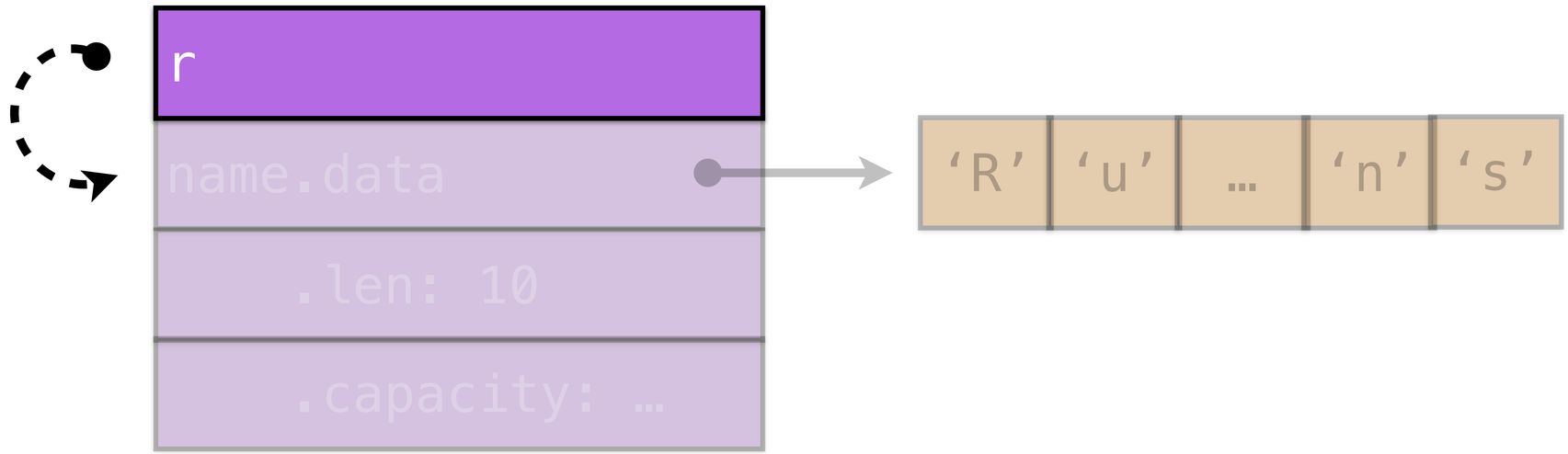

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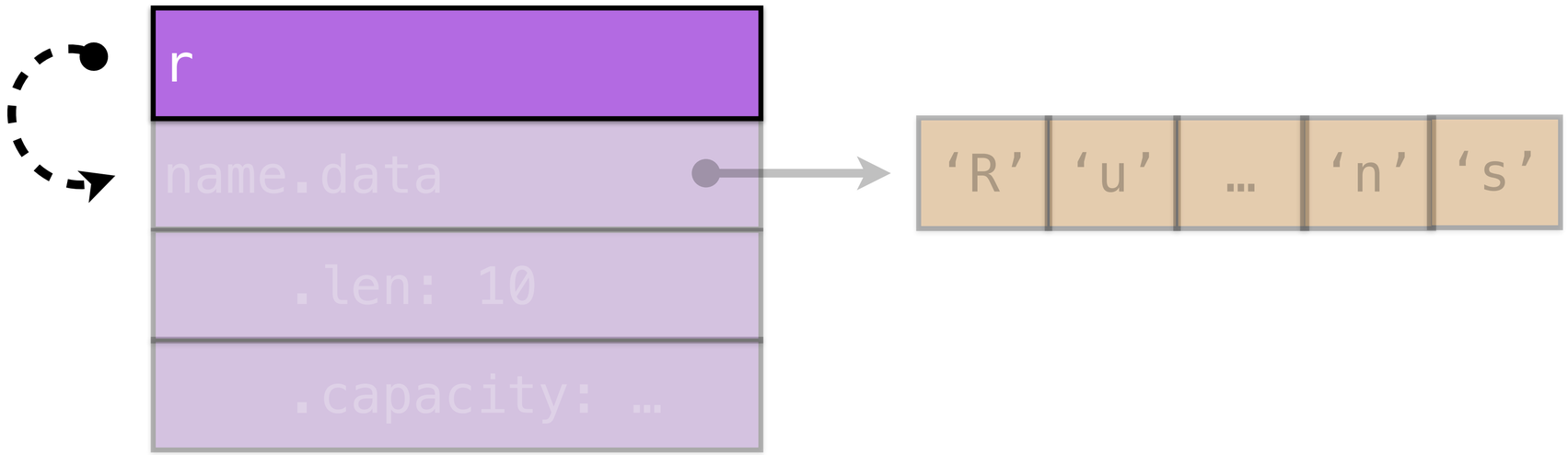

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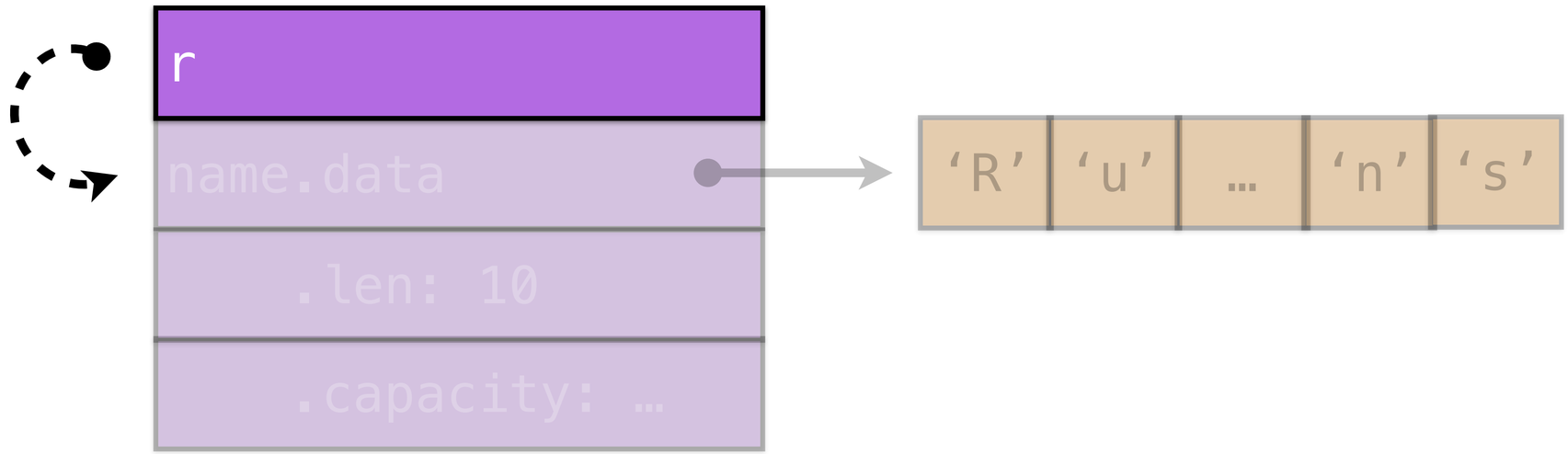

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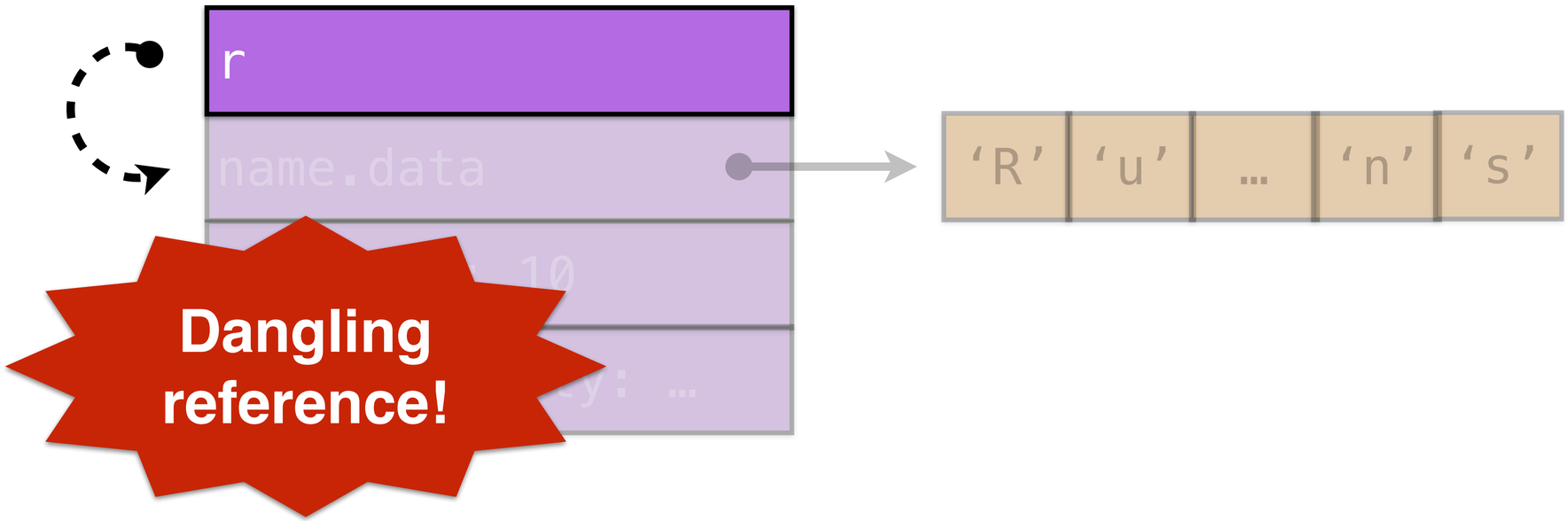

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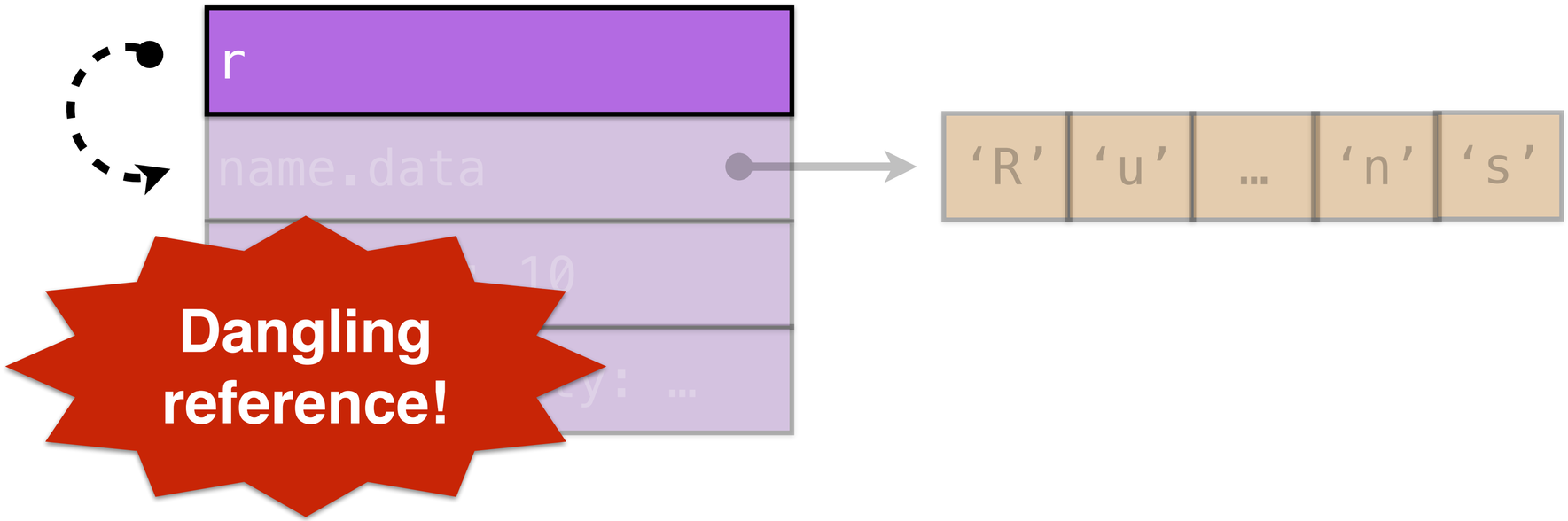

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  let r;
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    let name = format!("…");
    r = &name;
  }
  println!("{}", r);
}
```

http://is.gd/HJyO7A

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fn main() {
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    r = &name;
  }
  println!("{}", r);
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```

http://is.gd/HJyO7A

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fn main() {
  let r;
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    r = &name;
  }
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}
```

Lifetime: span of code where reference is used.

http://is.gd/HJyO7A

```
fn main() {
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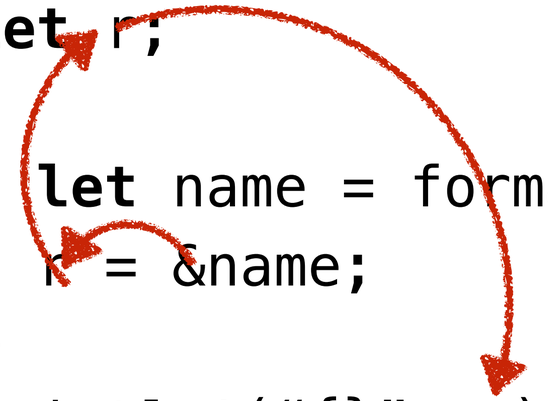

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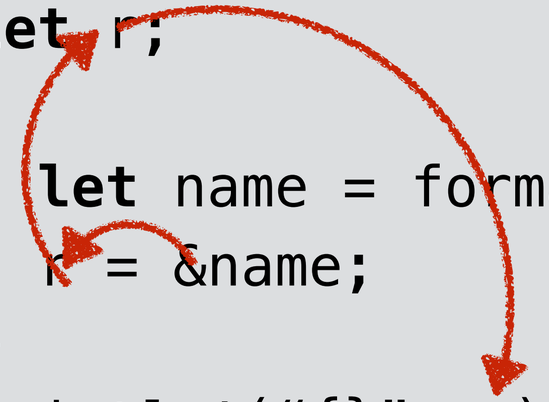

Lifetime: span of code where reference is used.

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Lifetime: span of code where reference is used.

http://is.gd/HJyO7A

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‘l

Lifetime: span of code where reference is used.

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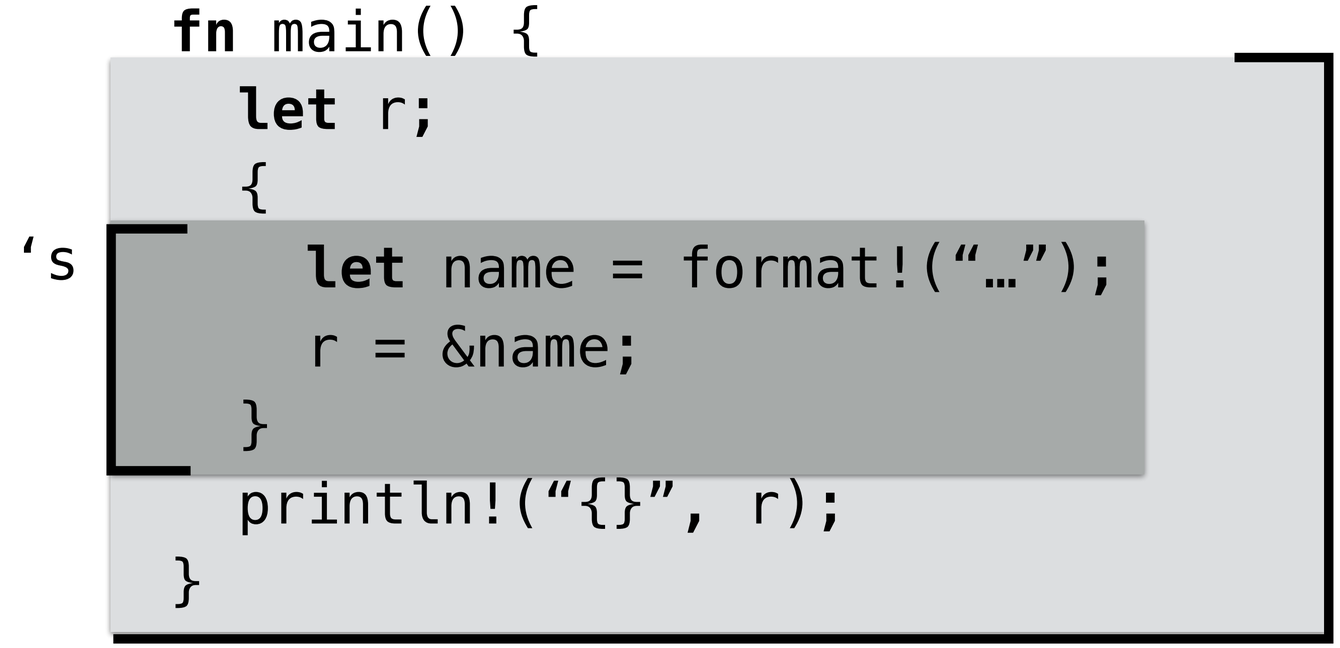
‘l

Lifetime: span of code where reference is used.

compared against

Scope of data being borrowed (here, `name`)

http://is.gd/HJyO7A



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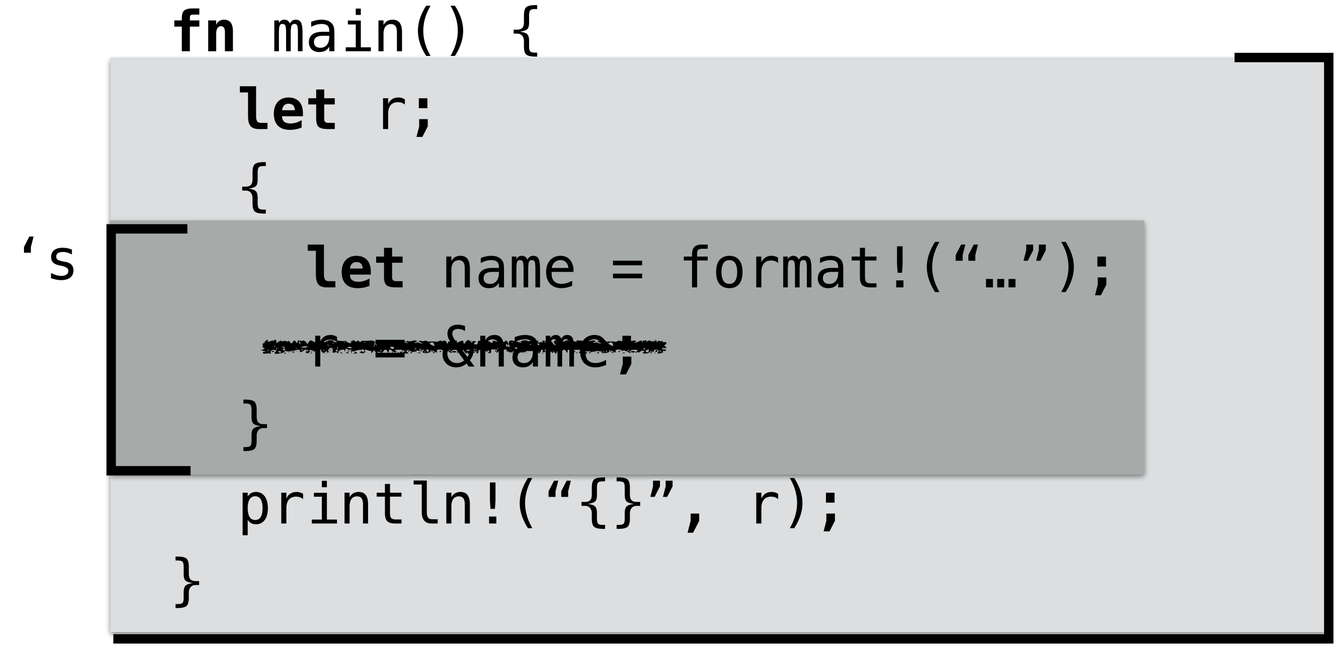
compared against

Scope of data being borrowed (here, `name`)

http://is.gd/HJyO7A



Lifetime: span of code where reference is used.

compared against

Scope of data being borrowed (here, `name`)

```
error: `name` does not live long enough
        r = &name;
             ^~~~
```

http://is.gd/HJyO7A

```
use std::thread;

fn helper(name: &String) {
  thread::spawn(move || {
    use(name);
  });
}
```

```
use std::thread;

fn helper(name: &String) {
  thread::spawn(move || {
    use(name);
  });
}
```

`name` can only be used within this fn

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use std::thread;

fn helper(name: &String) {
  thread::spawn(move || {
    use(name);
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use std::thread;

fn helper(name: &String) {
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        use(name);
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```

`name` can only be used within this fn

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use std::thread;

fn helper(name: &String) {
  thread::spawn(move || {
    use(name);
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Might escape the function!

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However: see **rayon**, **crossbeam**, etc on crates.io

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Dangers of mutation

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let mut buffer: String = format!(“Rustacean”);
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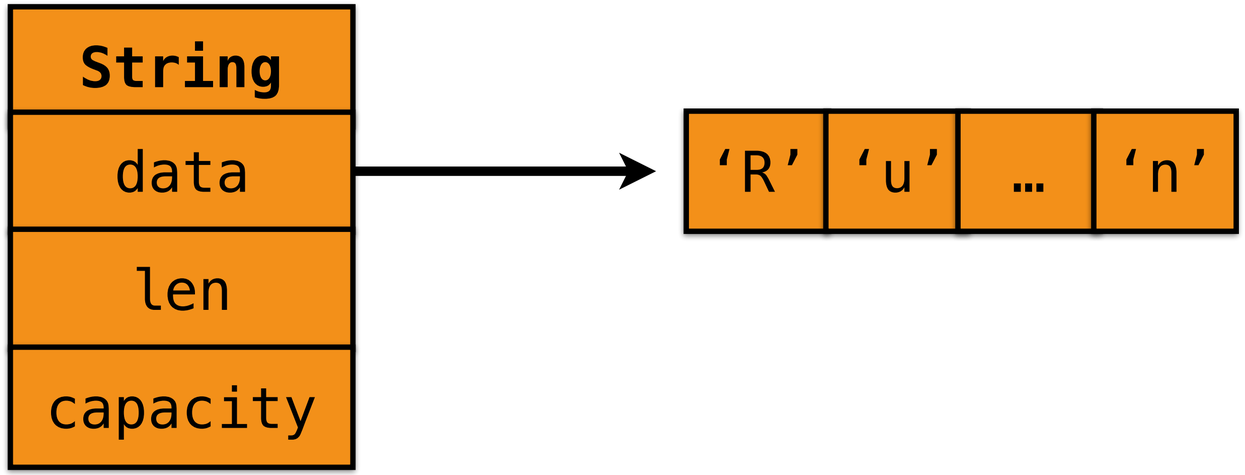

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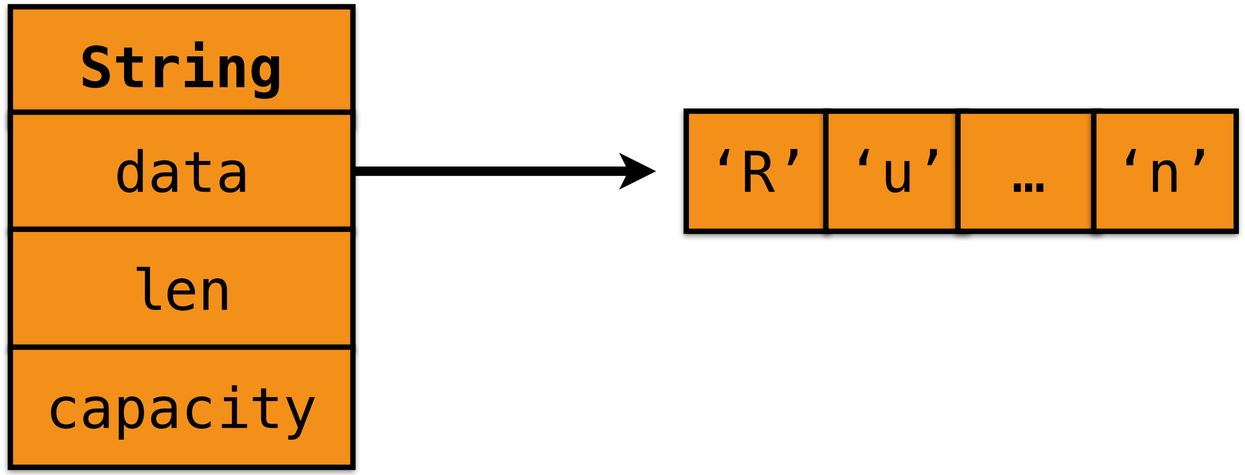

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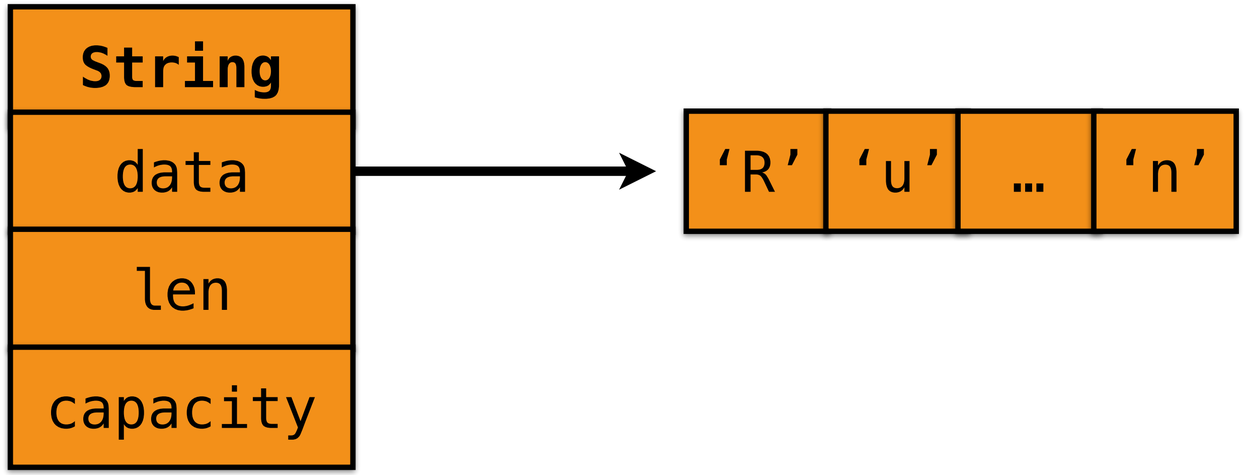

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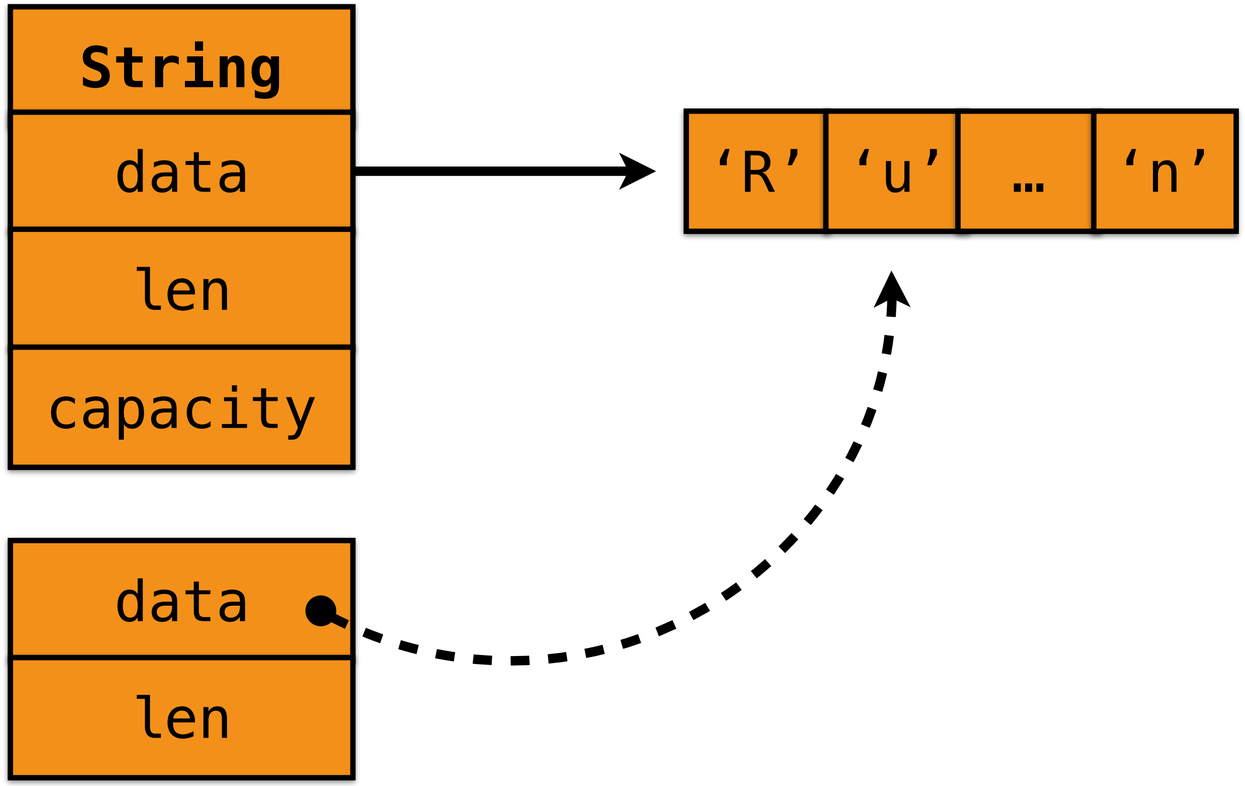

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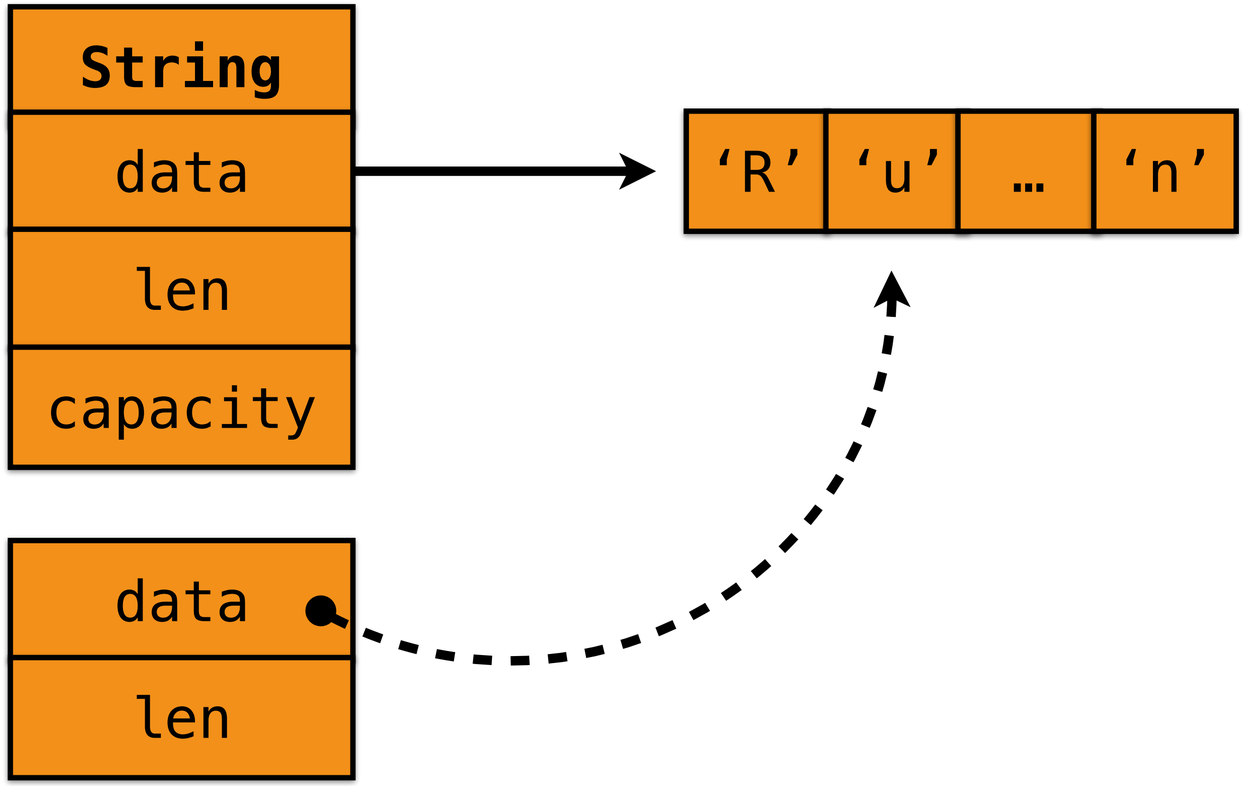

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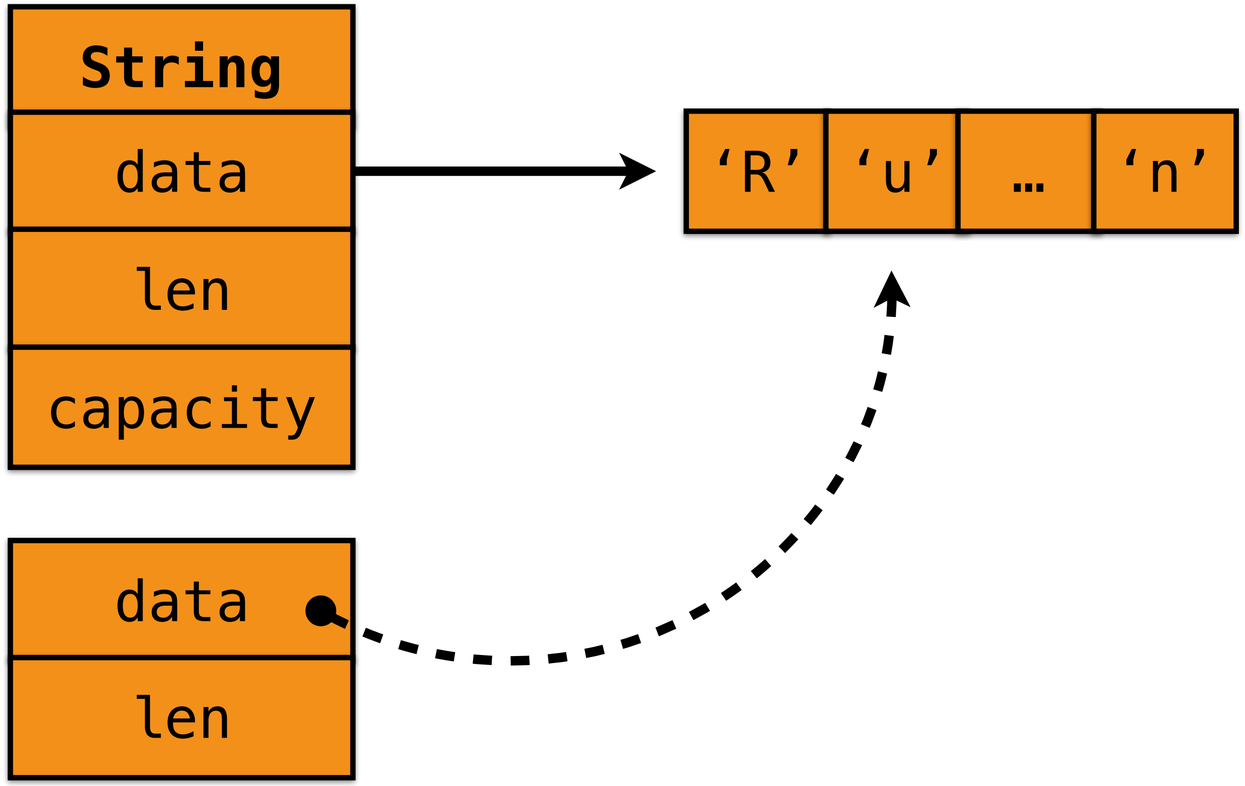

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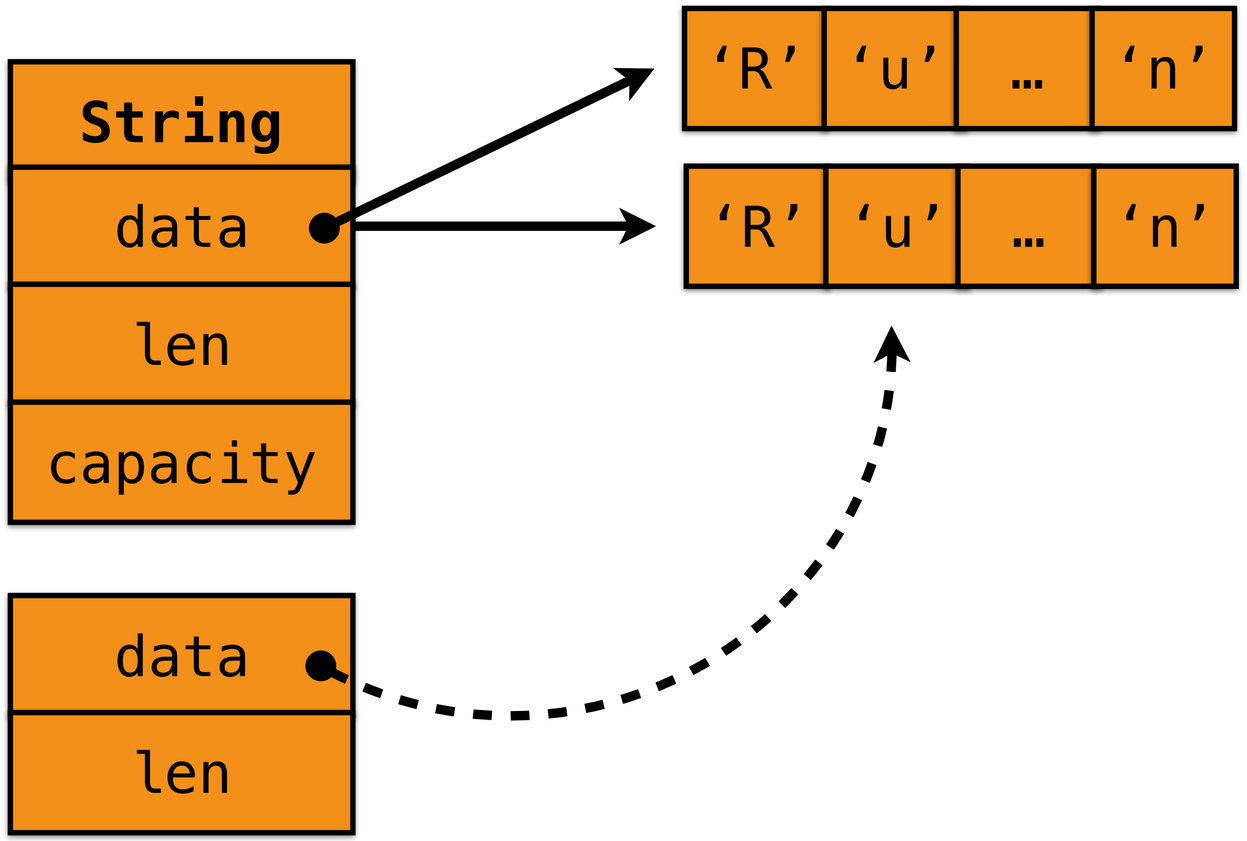

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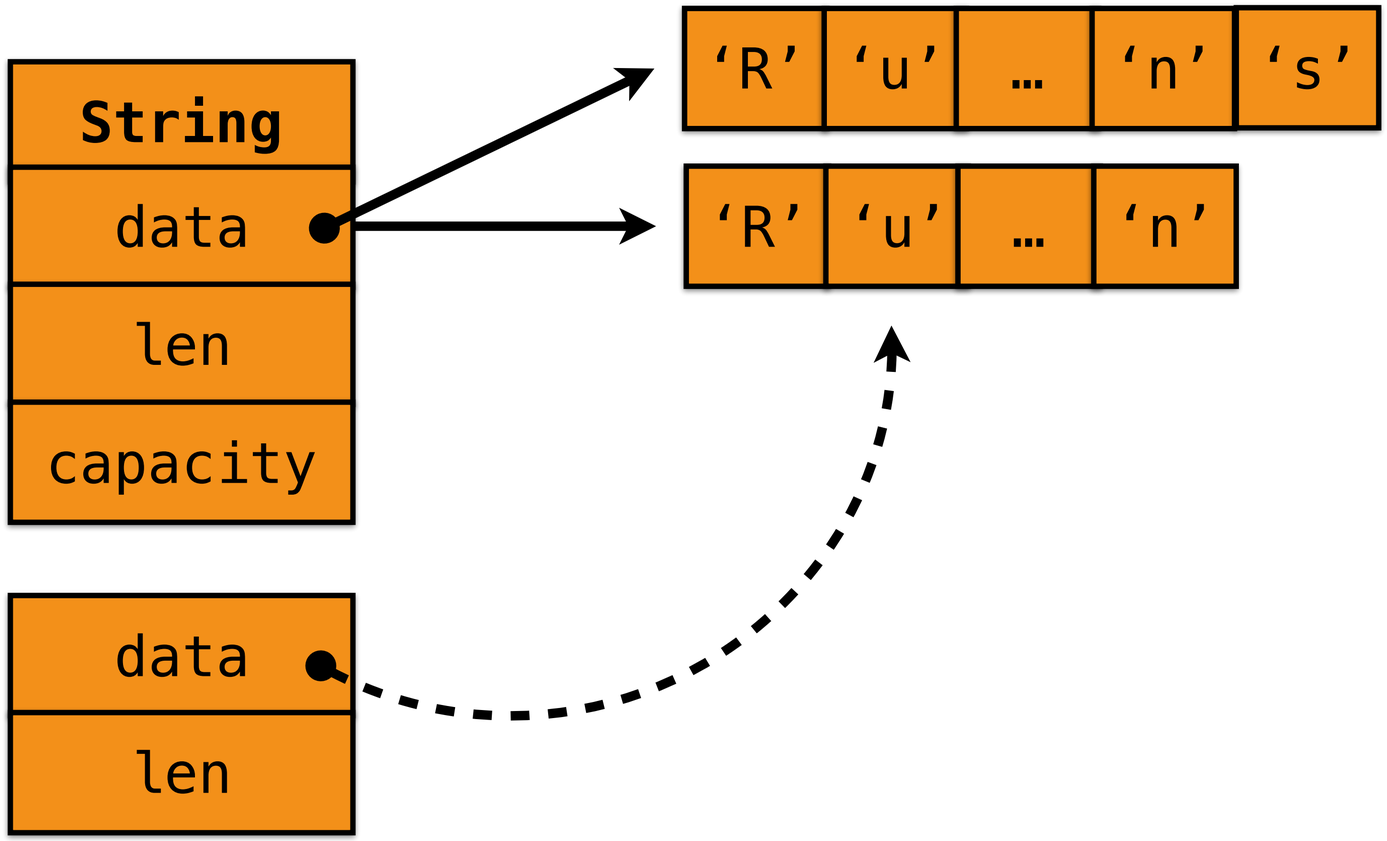

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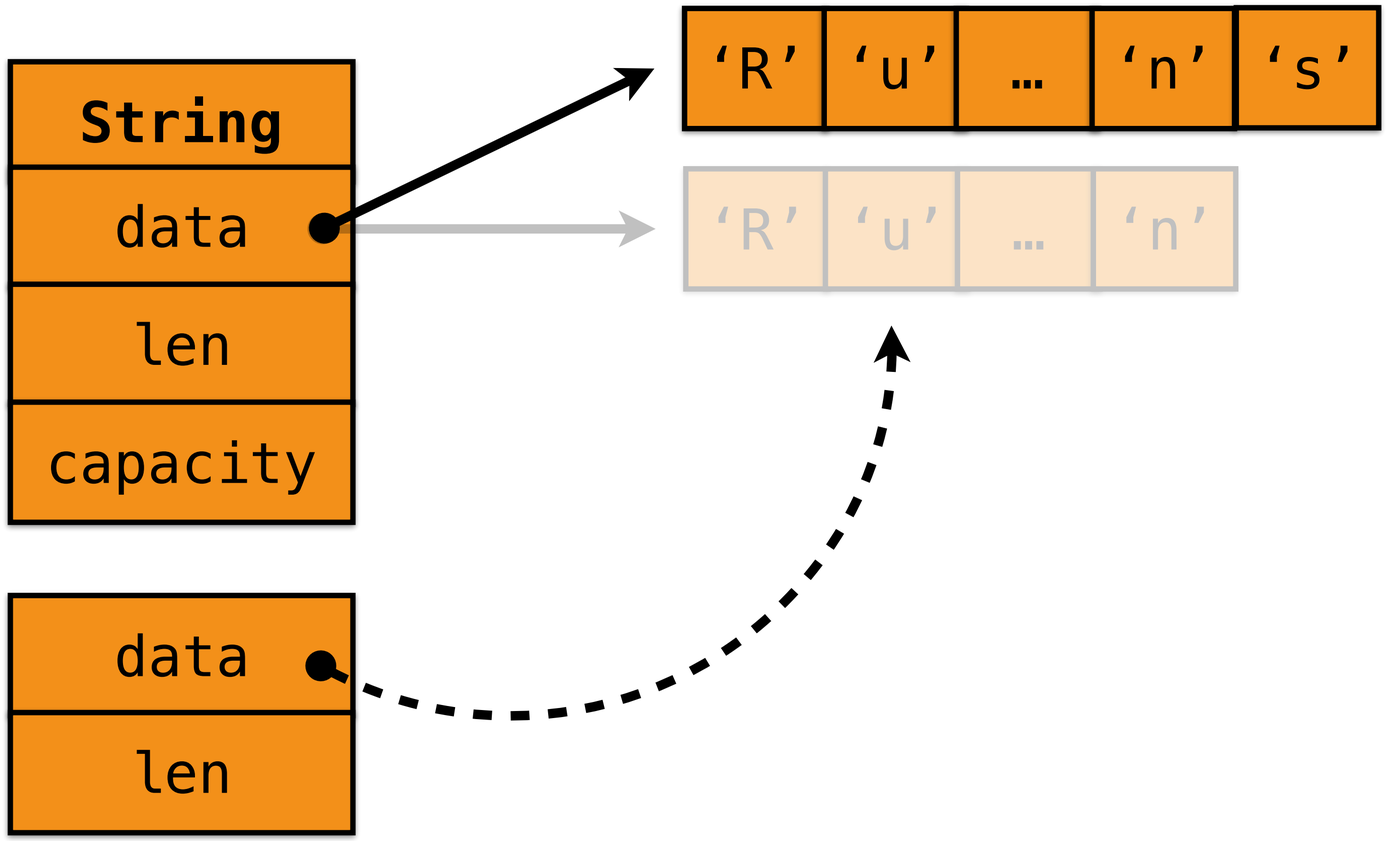

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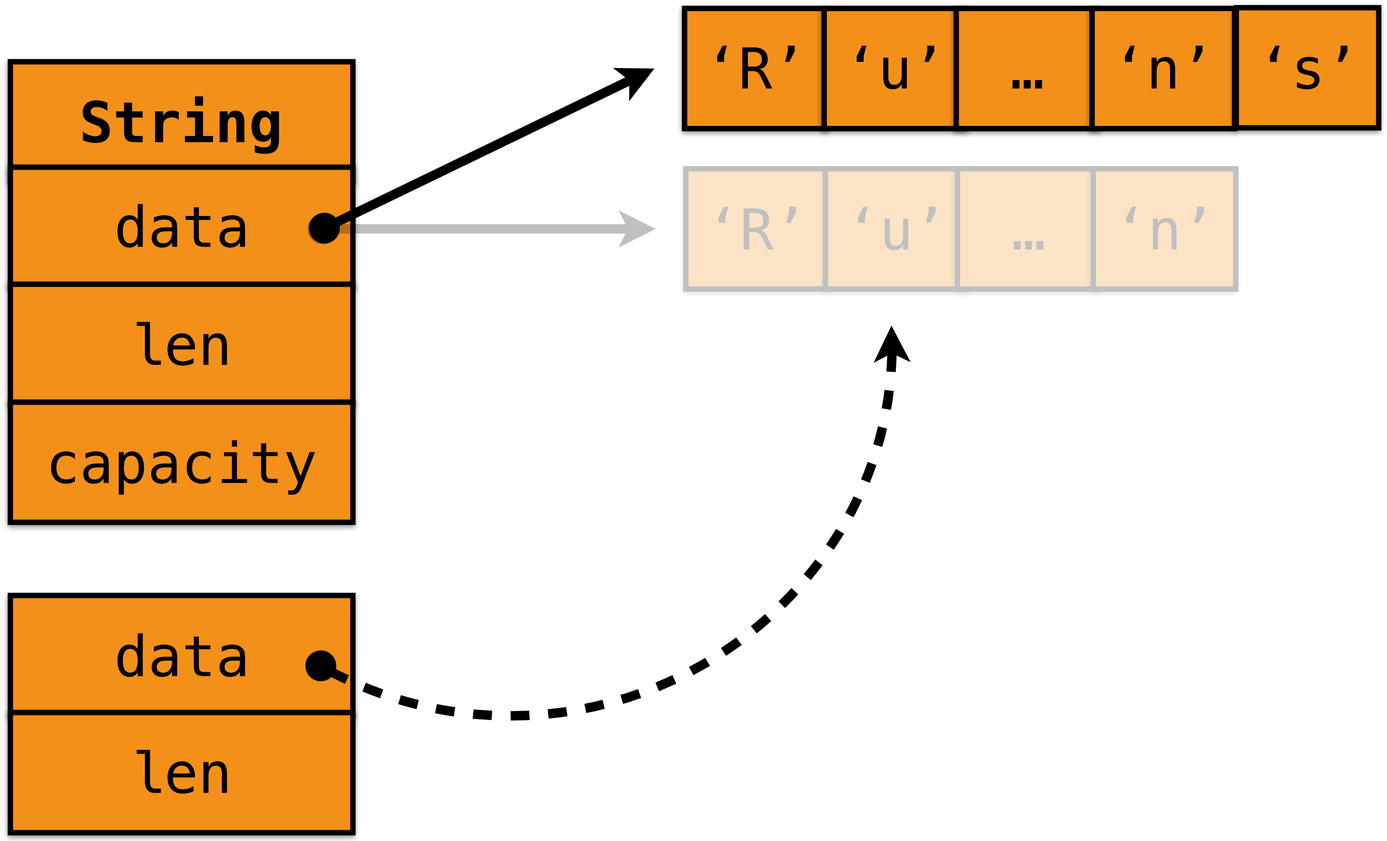

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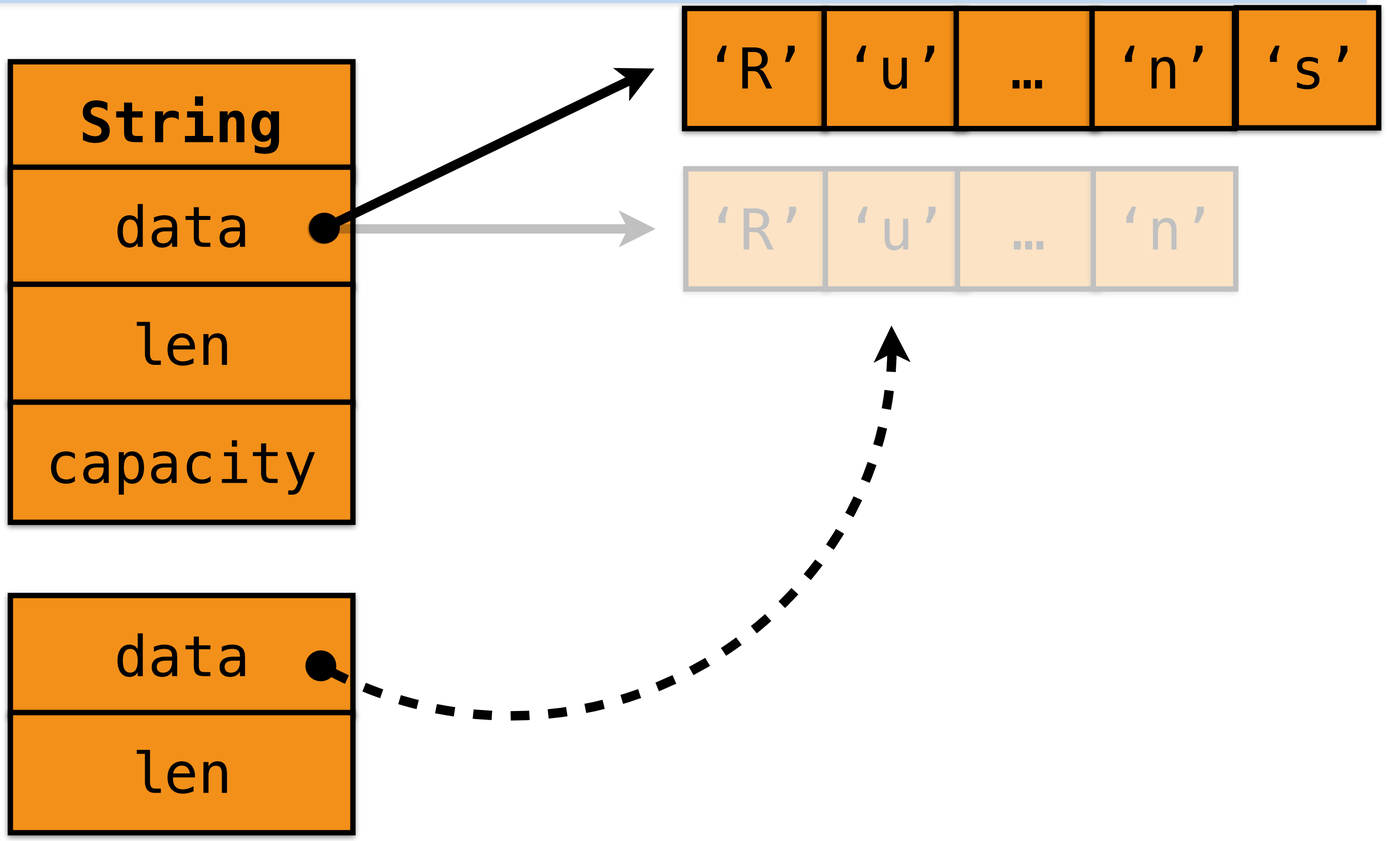

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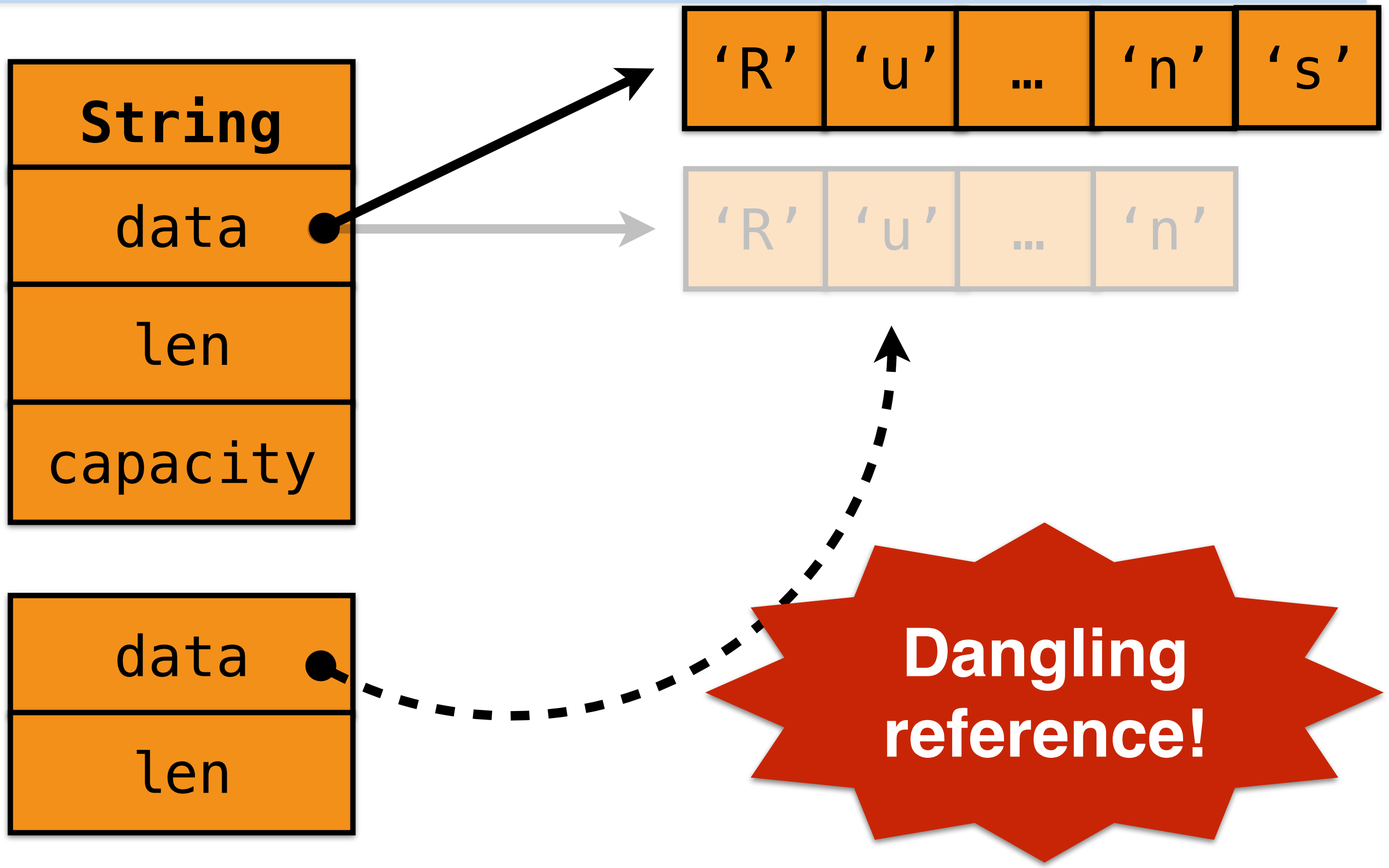

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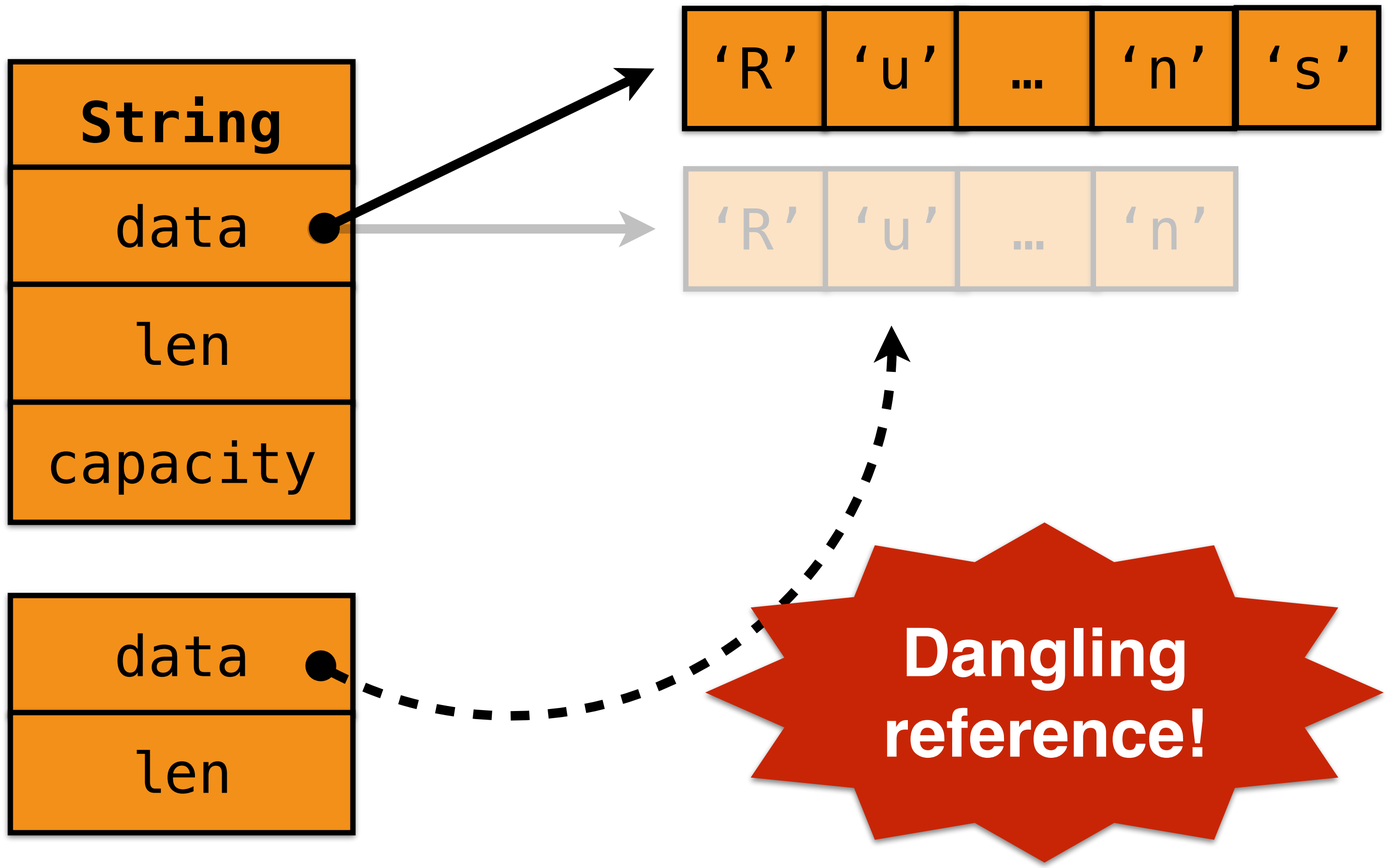

Rust solution

Compile-time read-write-lock:

Creating a shared reference to X **“read locks”** X.
- Other readers OK.
- No writers.
- Lock lasts until reference goes out of scope.

Creating a mutable reference to X **“writes locks”** X.
- No other readers or writers.
- Lock lasts until reference goes out of scope.

Never have a reader/writer at same time.

Dangers of mutation

```
fn main() {
  let mut buffer: String = format!(“Rustacean”);
  let slice = &buffer[1..];
  buffer.push_str(“s”);
  println!(“{:?}”, slice);
}
```

http://is.gd/MCPVWg

Dangers of mutation

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Borrow “locks” `buffer` until `slice` goes out of scope

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error: cannot borrow `buffer` as mutable
       because it is also borrowed as immutable
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```
fn main() {
  let mut buffer: String = format!(“Rustacean”);
  for i in 0 .. buffer.len() {
    let slice = &buffer[i..];
    buffer.push_str(“s”);
    println!(“{:?}”, slice);
  }
  buffer.push_str(“s”);
}
```

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Borrow “locks” `buffer` until `slice` goes out of scope

OK: `buffer` is not borrowed here

Exercise: **mutable borrow**

http://rust-tutorials.com/exercises/

Cheat sheet:

```
&String          // type of shared reference
&mut String      // type of mutable reference
&str             // type of string slice

fn greet(name: &String) {..}
fn adjust(name: &mut String) {..}

&name            // shared borrow
&mut name        // mutable borrow
&name[x..y]      // slice expression
```

http://doc.rust-lang.org/std

Thanks for listening!

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Try this next!

★ structs and such