Pre-processing for good suffix

- For a given i, let $k{=}|P|{-}i{+}1$, i.e., the length of $P[i, |P|]$
  - Let $L(i){=}j{<}|P|$ be the largest position such that $P[i, |P|]$ matches $P[j{-}k{+}1, j]$ and $P(j{-}k) \neq P(i{-}1)$
  - If no such j exists, $L(i) = 0$
- Let $l(i)$ be the length of the largest suffix of $P(i, |P|)$ that is also a prefix
- These can be calculated in linear time (see Gusfield)

Pre-processing for Boyer-Moore

Position:	1	2	3	4	5	6
String:	x	t	p	x	t	d
Z_i:		0	0	2	0	0
$L(i)$:		0	0	0	0	0
$l(i)$:		0	0	0	0	0

$$R(x) = 4$$

$$R(t) = 5$$

$$R(p) = 3$$

$$R(d) = 6$$

Using good suffix and bad character

- Using simple bad character and strong good suffix
- Bad character: shift P by $\max(1, i - R(T(k)))$
- Good suffix:
  - If an occurrence of P is found then shift P by $|P| - l(2)$
  - Else if $i = |P|$ then advance P by 1
  - Else if mismatch is at $i{-}1$ of P and $L(i) > 0$ then shift P by $|P| - L(i)$
  - Else shift P by $|P| - l(i)$
- Shift by the max of these two rules

For current example

- All $l(i)$ and $L(i)$ are 0, hence Good Suffix rule becomes:
  - If $i = |P|$ and no match, advance by 1
  - otherwise if no match, advance by $|P|$

Boyer-Moore

```
x l u x t p x t d q w t d x t p x t s y x t p x t d y
x t p x t d
          ↑
```

Align both strings at their beginning position and begin comparing from the last character of P

Comparisons: 1

$\boldsymbol{R(x) = 4; R(t) = 5; R(p) = 3; R(d) = 6}$

Boyer-Moore

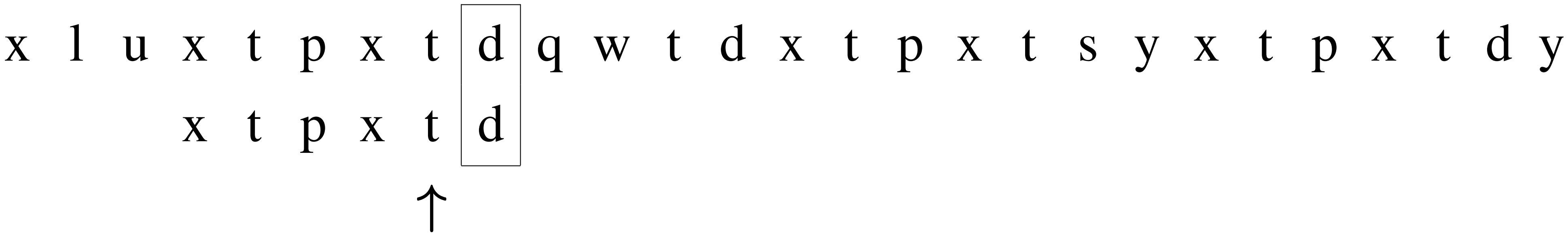
```
x l u x t p x t d q w t d x t p x t s y x t p x t d y
      x t p x t d
                ↑
```

If symbols don't match, shift P by the max of the good suffix and bad character rules

Comparisons: 2

$R(p) = 3$, hence bad character: shift max(1,6-3)=3
$i = |P|$, hence good suffix: shift 1

Boyer-Moore

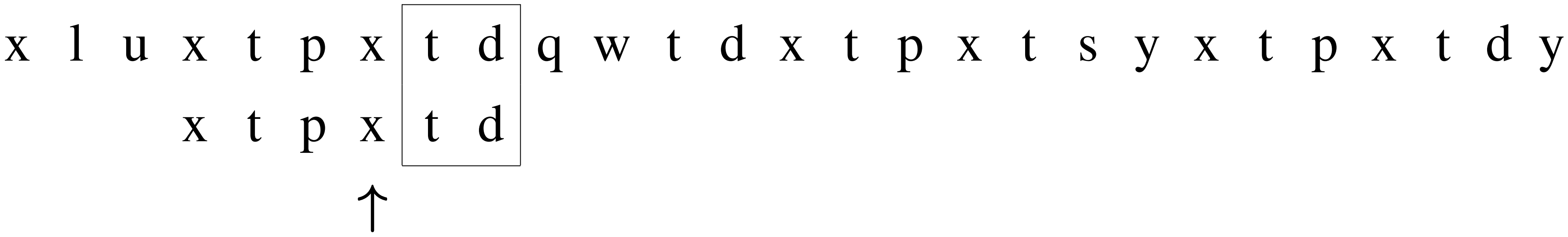


```
x l u x t p x t d q w t d x t p x t s y x t p x t d y
      x t p x t d
              ↑
```

If symbols match, compare previous symbols

Comparisons: 3

Boyer-Moore

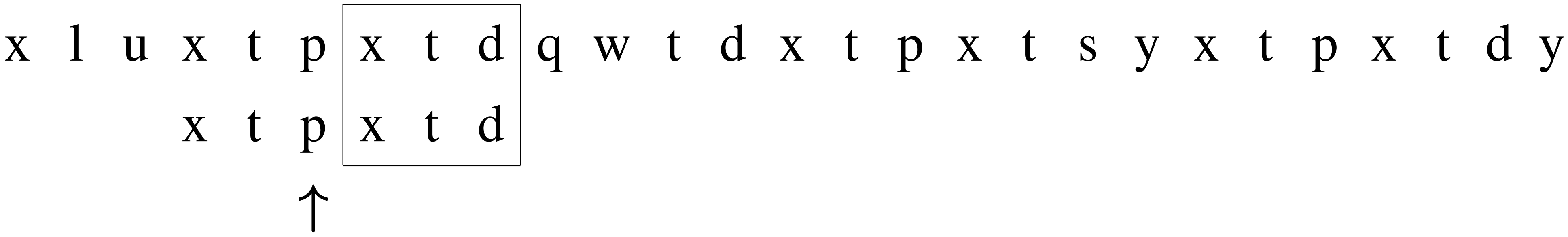


```
x l u x t p x t d q w t d x t p x t s y x t p x t d y
      x t p x t d
            ↑
```

If symbols match, compare previous symbols

Comparisons: 4

Boyer-Moore



x l u x t p x t d q w t d x t p x t s y x t p x t d y

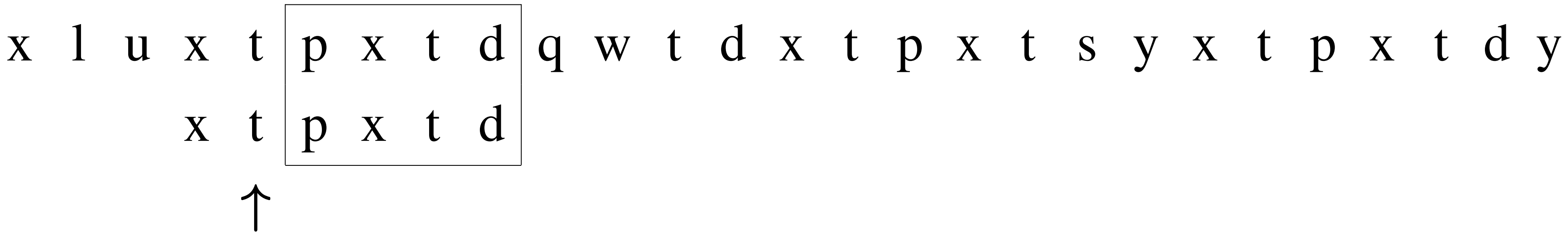
x t p x t d

↑

If symbols match, compare previous symbols

Comparisons: 5

Boyer-Moore



x l u x t p x t d q w t d x t p x t s y x t p x t d y

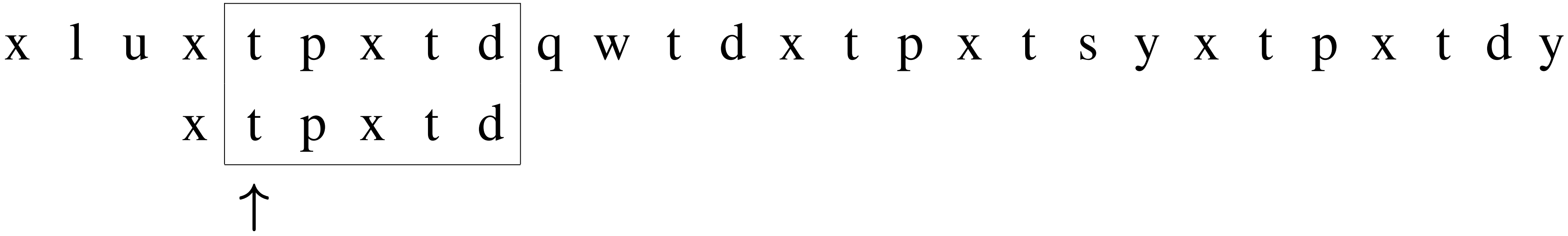
x t p x t d

↑

If symbols match, compare previous symbols

Comparisons: 6

Boyer-Moore



x l u x t p x t d q w t d x t p x t s y x t p x t d y

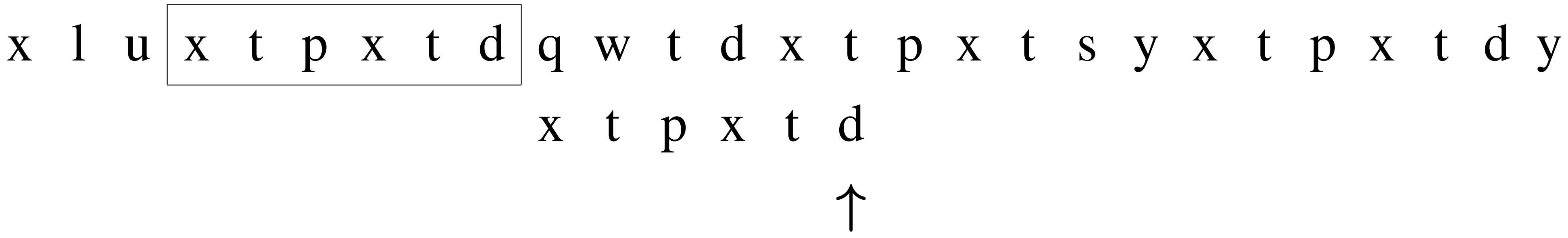
x t p x t d

↑

If symbols match, compare previous symbols

Comparisons: 7

Boyer-Moore



x l u x t p x t d q w t d x t p x t s y x t p x t d y

x t p x t d

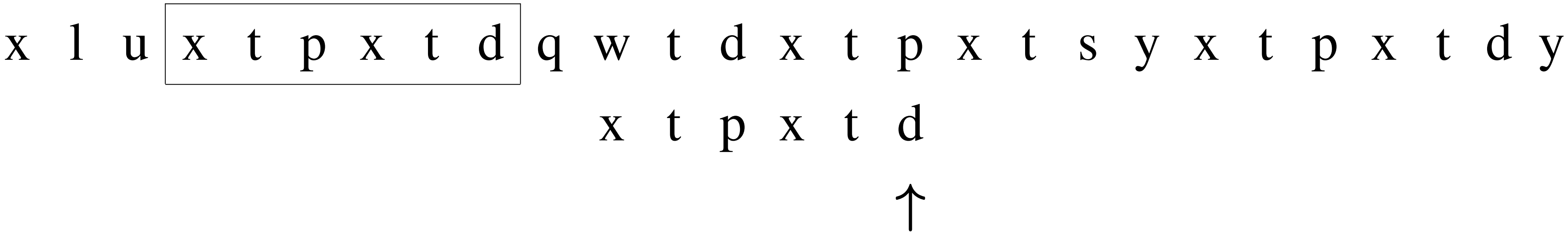
↑

If P is found, shift P by $|P| - l(2)$, begin at end

Comparisons: 8

$$R(x) = 4; R(t) = 5; R(p) = 3; R(d) = 6$$

Boyer-Moore



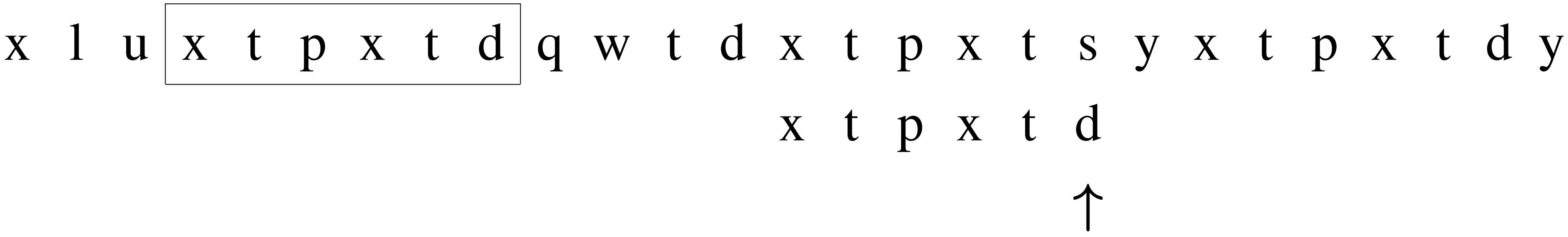
```
x l u x t p x t d q w t d x t p x t s y x t p x t d y
                    x t p x t d
                              ↑
```

If symbols don't match, shift P by the max of the good suffix and bad character rules

Comparisons: 9

$\boldsymbol{R(t) = 5}$**, hence bad character: shift max(1,6-5)=1**
$\boldsymbol{i = |P|}$**, hence good suffix: shift 1**

Boyer-Moore



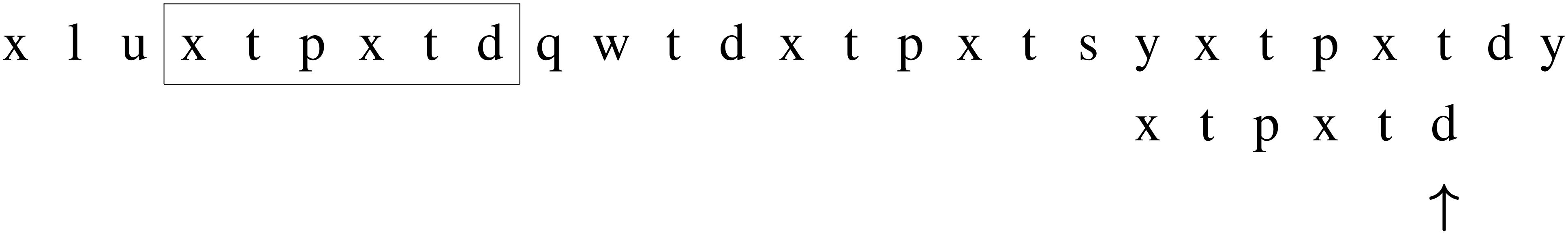
```
x l u x t p x t d q w t d x t p x t s y x t p x t d y
                          x t p x t d
                                    ↑
```

If symbols don't match, shift P by the max of the good suffix and bad character rules

Comparisons: 10

$R(p) = 3$, hence bad character: shift max(1,6-3)=3
$i = |P|$, hence good suffix: shift 1

Boyer-Moore



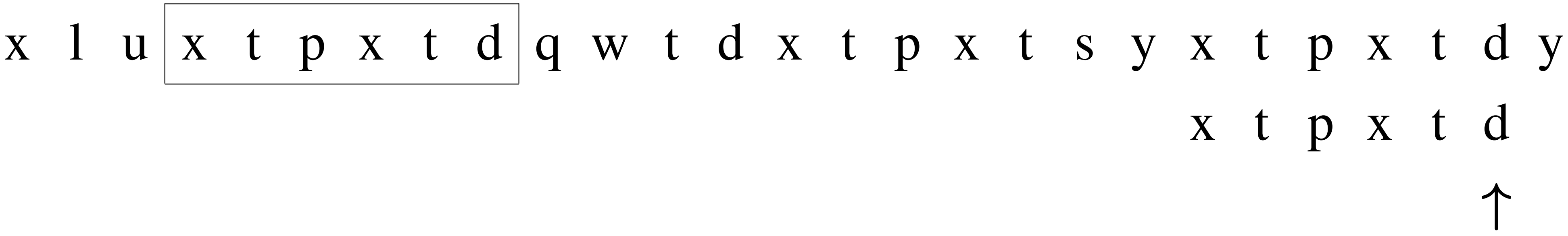
```
x l u x t p x t d q w t d x t p x t s y x t p x t d y
                                      x t p x t d
                                                ↑
```

If symbols don't match, shift P by the max of the good suffix and bad character rules

Comparisons: 11

$R(s) = 0$, hence bad character: shift max(1,6-0)=6
$i = |P|$, hence good suffix: shift 1

Boyer-Moore



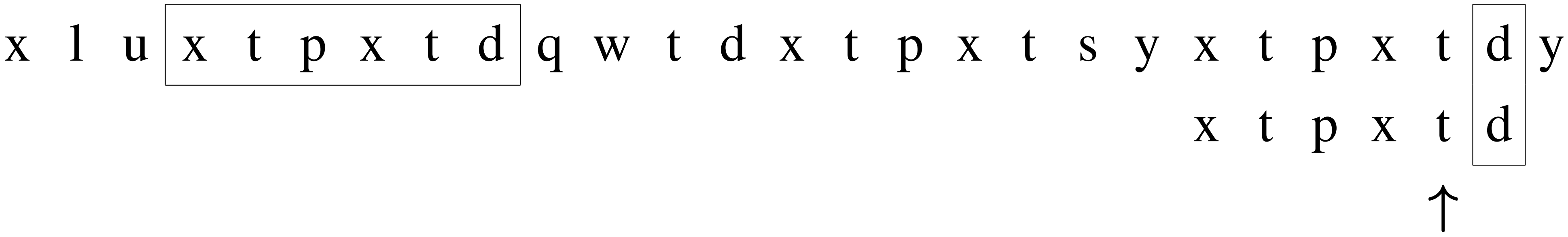
```
x l u x t p x t d q w t d x t p x t s y x t p x t d y
                                        x t p x t d
                                                  ↑
```

If symbols don't match, shift P by the max of the good suffix and bad character rules

Comparisons: 12

$\boldsymbol{R(t) = 5}$**, hence bad character: shift max(1,6-5)=1**
$\boldsymbol{i = |P|}$**, hence good suffix: shift 1**

Boyer-Moore

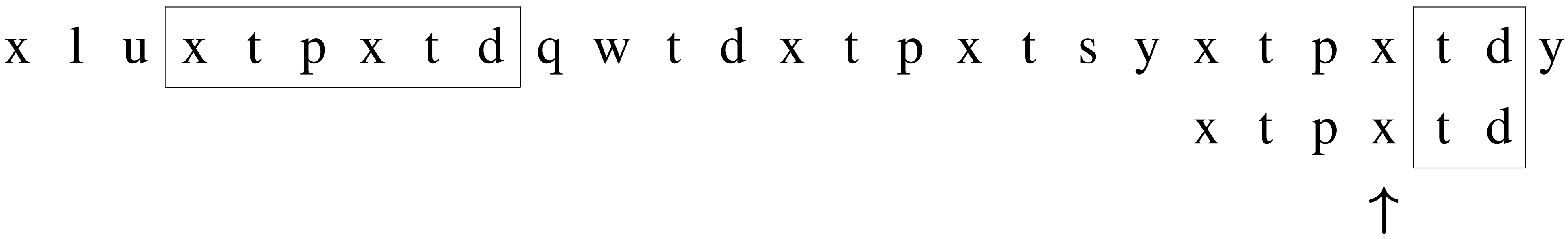


```
x l u x t p x t d q w t d x t p x t s y x t p x t d y
                                        x t p x t d
                                                ↑
```

If symbols match, compare previous symbols

Comparisons: 13

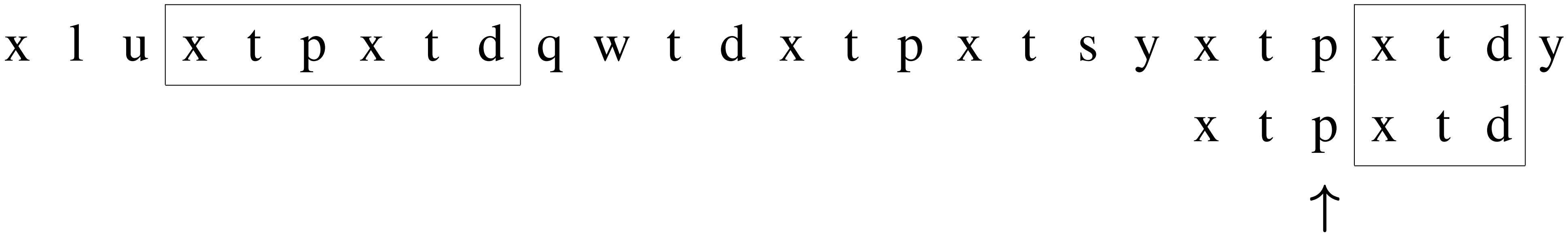
Boyer-Moore



If symbols match, compare previous symbols

Comparisons: 14

Boyer-Moore



x l u x t p x t d q w t d x t p x t s y x t p x t d y

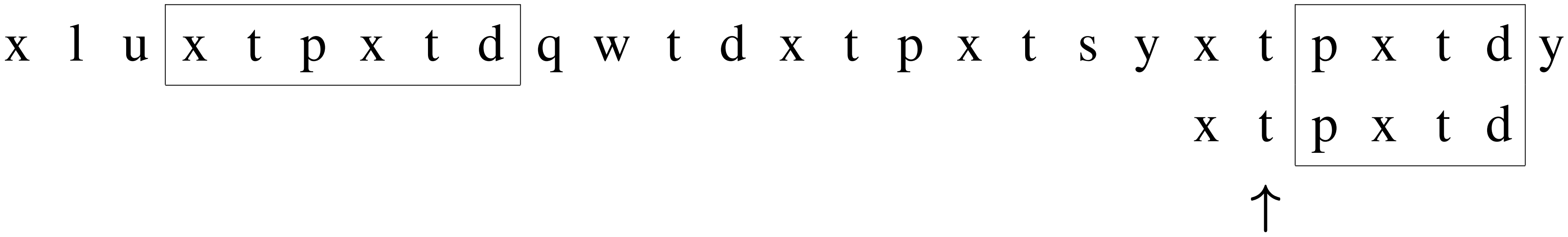
x t p x t d

↑

If symbols match, compare previous symbols

Comparisons: 15

Boyer-Moore



x l u x t p x t d q w t d x t p x t s y x t p x t d y

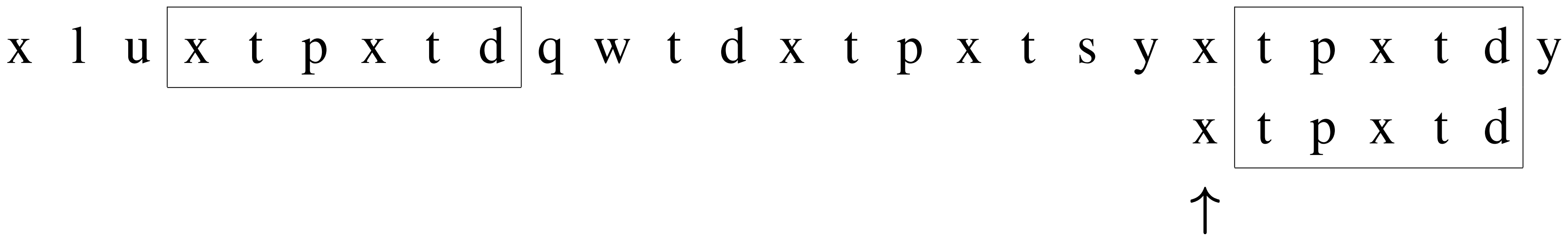
x t p x t d

↑

If symbols match, compare previous symbols

Comparisons: 16

Boyer-Moore



x l u x t p x t d q w t d x t p x t s y x t p x t d y

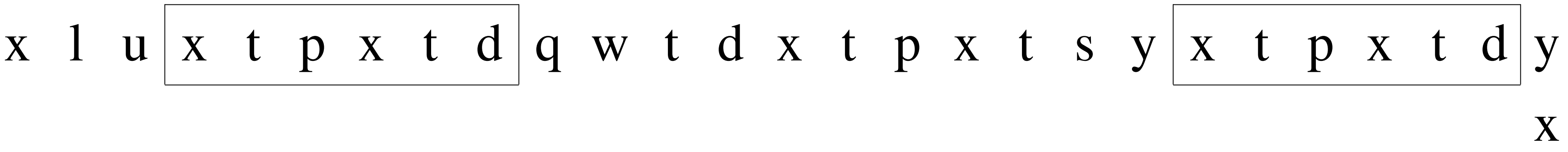
x t p x t d

↑

If symbols match, compare previous symbols

Comparisons: 17

Boyer-Moore



x l u x t p x t d q w t d x t p x t s y x t p x t d y

x

If P is found, shift P by $|P| - l(2)$, begin at end (past end... finished)

Comparisons: 17

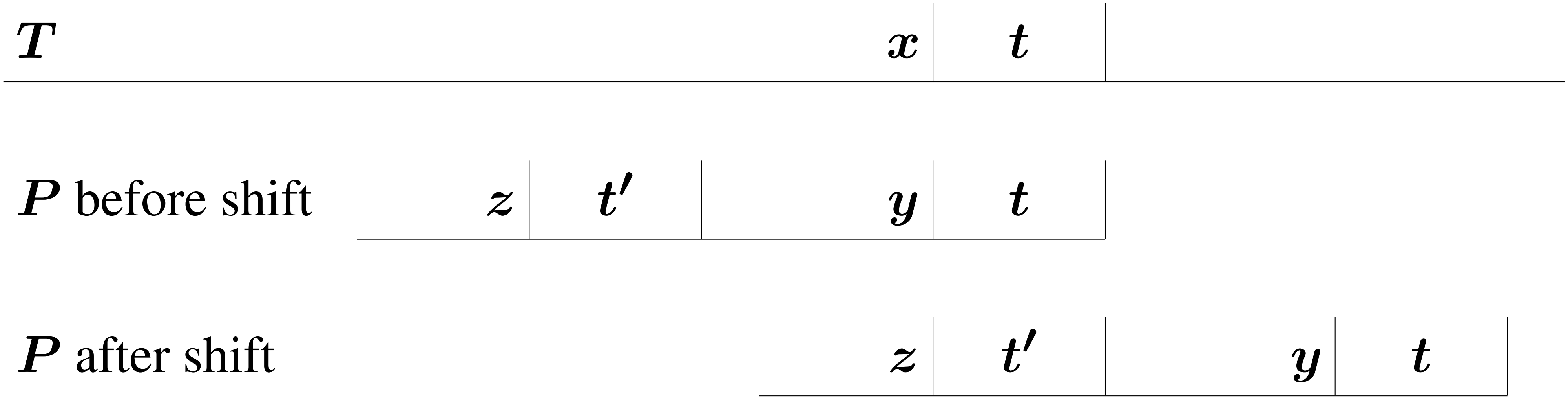
vs. 42 for naive algorithm and
30 for Knuth-Morris-Pratt

Boyer Moore algorithm

- **Current example does not show some parts of Boyer Moore that are de-emphasized in the text**
- **When using the good suffix for shifting with $L(i)$ or $l(i)$, some of string is already matched**
- **Without skipping already matched material, lots of duplicate effort**

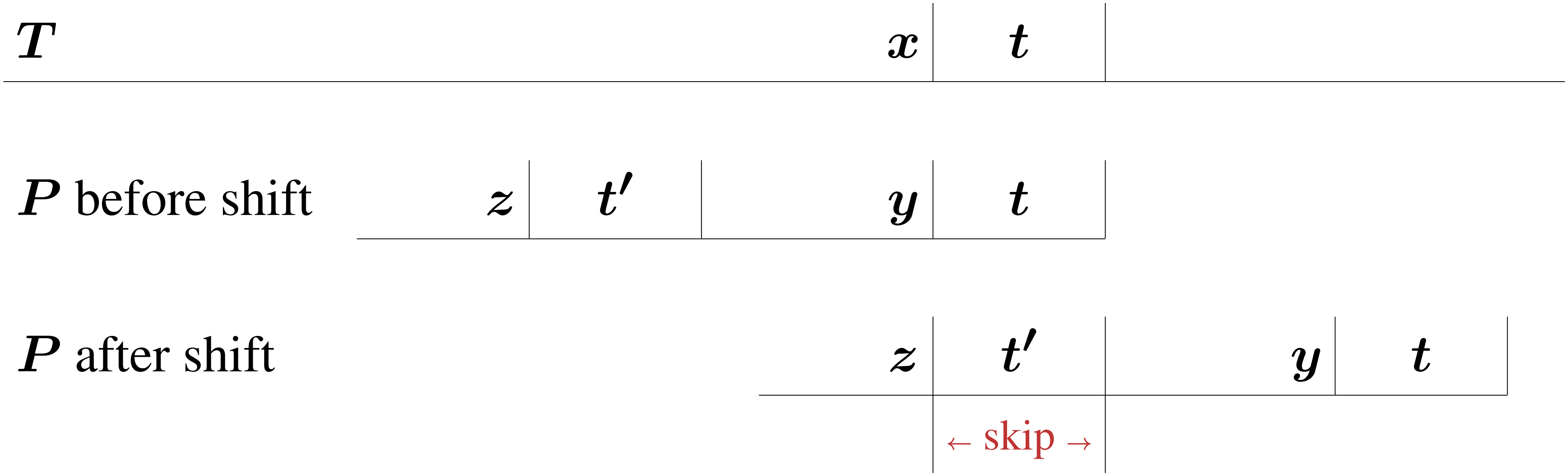
Good suffix rule (strong)

Illustration from Gusfield



Good suffix rule (strong)

Illustration from Gusfield



T x t

P before shift z t' y t

P after shift z t' y t

← skip →

Algorithm in Gusfield Text

```
$k \leftarrow |P|$
while $k \leq |T|$
    $i \leftarrow |P|$
    $h \leftarrow k$
    while $i > 0$ and $P(i) = T(h)$
        $i \leftarrow i - 1$
        $h \leftarrow h - 1$
    if $i = 0$
        found $P$ ending at $k$
        $k \leftarrow k + |P| - l'(2)$
    else
        $k \leftarrow k + \max(\text{bad-char, good-suffix})$
```

More to keep track of

```
$k \leftarrow |P|$
while $k \leq |T|$
    $i \leftarrow |P|$
    $h \leftarrow k$
    while $i > 0$ and $P(i) = T(h)$
        $i \leftarrow i - 1$
        $h \leftarrow h - 1$                              ← may need to skip over some
    if $i = 0$
        found $P$ ending at $k$
        $k \leftarrow k + |P| - l'(2)$                         ← anything to skip over?
    else
        $k \leftarrow k + \max(\text{bad-char, good-suffix})$     ← anything to skip over?
```