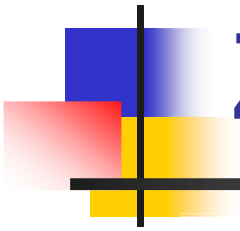
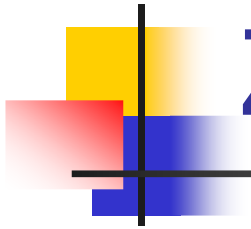


Felder (Arrays) und Zeiger (Pointers) - Teil II

Zeichen, Texte, String Matching;
Mehrdimensionale Felder;
kürzeste Wege



Zeichen und Texte

- Texte haben wir schon gesehen:

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std::cout << "Prime numbers in {2,...,999}:\n";
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String-Literal

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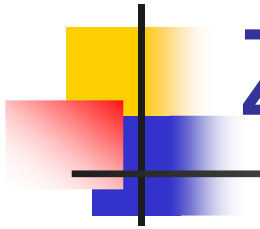

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std::cout << "Prime numbers in {2,...,999}:\n";
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String-Literal

- Können wir auch “richtig” mit Texten arbeiten?

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std::cout << "Prime numbers in {2,...,999}:\n";
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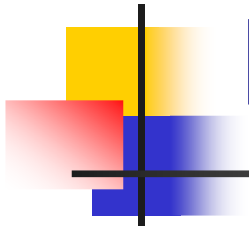
String-Literal

- Können wir auch "richtig" mit Texten arbeiten? Ja:

Zeichen:	Wert des fundamentalen Typs **`char`**
Text:	Feld mit zugrundeliegendem Typ **`char`**



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- repräsentiert druckbare Zeichen (z.B. **`'a'`**) und *Steuerzeichen* (z.B. **`'\n'`**)

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definiert Variable c vom Typ **`char`** mit Wert **`'a';`**

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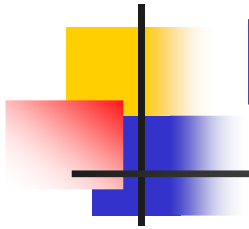
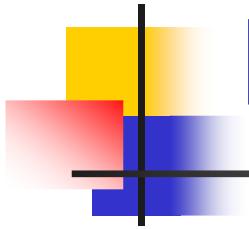


Der Typ **`char`** (“character”)

- ist formal ein ganzzahliger Typ
  - Werte konvertierbar nach **`int`** / **`unsigned int`**
  - Alle arithemtischen Operatoren verfügbar (Nutzen zweifelhaft: was ist **`'a'/'b'`** ?)



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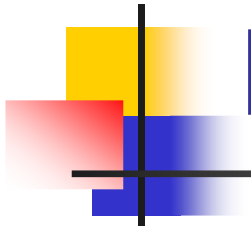
  - Werte belegen meistens 8 Bit

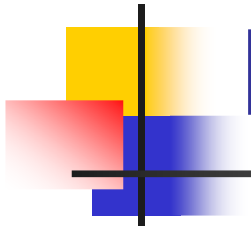
Wertebereich:

{-128,...,127} oder {0,...,255}



Der ASCII-Code

- definiert konkrete Konversionregeln
  `char` $\rightarrow$ **`int / unsigned int`**
- wird von fast allen Plattformen benutzt



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Zeichen → {0,...,127}

`'A','B',...,'Z'` → 65, 66,...,90

`'a','b',...,'z'` → 97, 98,...,122

Der ASCII-Code

```
for (char c = 'a'; c <= 'z'; ++c)
   std::cout << c;
```

Ausgabe: **abcdefghijklmnopqrstuvwxyz**

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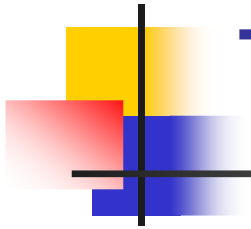

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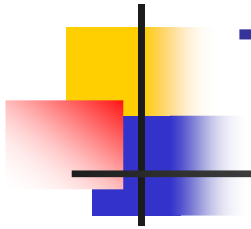

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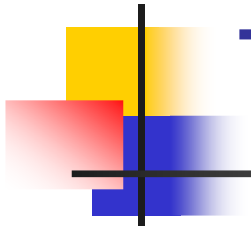
char text[] = {'b', 'o', 'o', 'l'}
```

definiert ein Feld der Länge 4,
das dem Text “bool” entspricht



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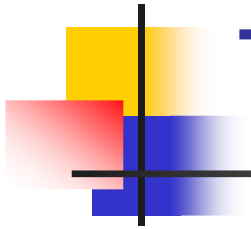

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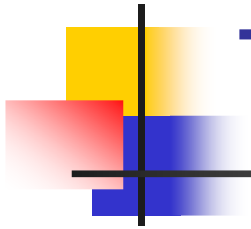

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"speichert" seine Länge!

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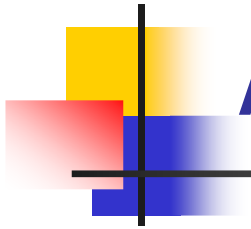

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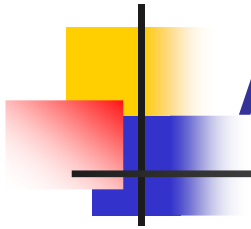
Finde das erste (oder alle) Vorkommen eines Musters (meist kurz) in einem gegebenen Text (meist lang)!



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"Trivialer" Algorithmus:

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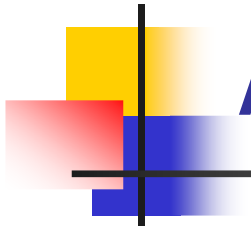

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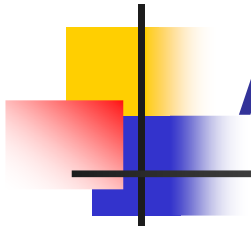

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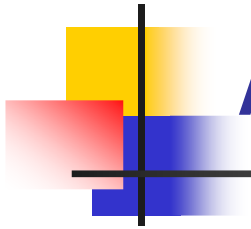

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                        visa
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Anwendung: *String matching*

```
#include<iostream>

int main ()
{
  // search string
  const char s[] = "bool";

  // determine search string length m
  unsigned int m = 0;
  for (const char* p = s; *p != '\0'; ++p) ++m;

  // cyclic text window of size m
  char* const t = new char[m];

  unsigned int w = 0; // number of characters read so far
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Muster “fest verdrahtet” in diesem Program (aber siehe *Details* im Skript)

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Rechne die Musterlänge aus (das geht, weil **s** null-terminiert ist)

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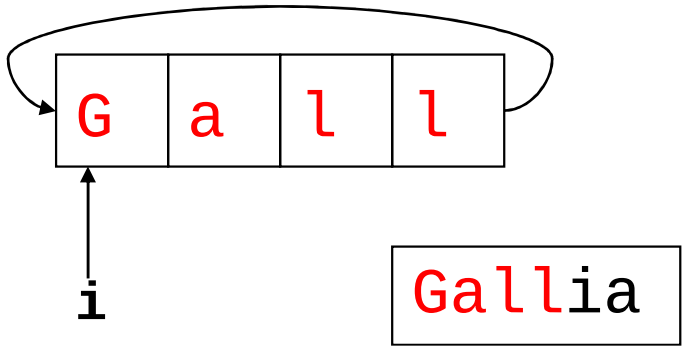

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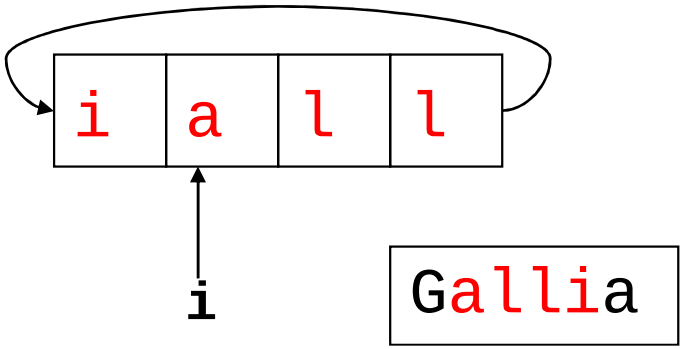

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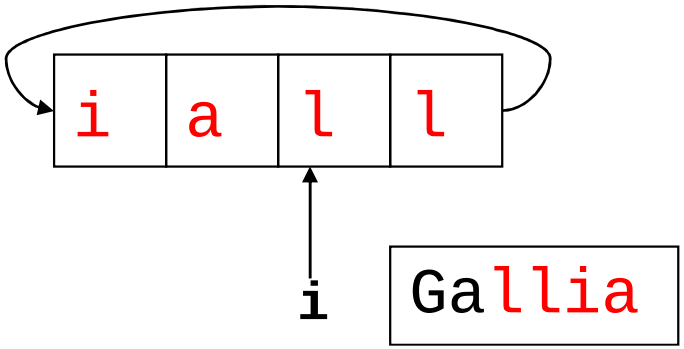

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  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
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      if (std::cin >> t[i]) {
        std::cout << t[i];
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Leerzeichen und Zeilenumbrüche sollen *nicht* ignoriert werden

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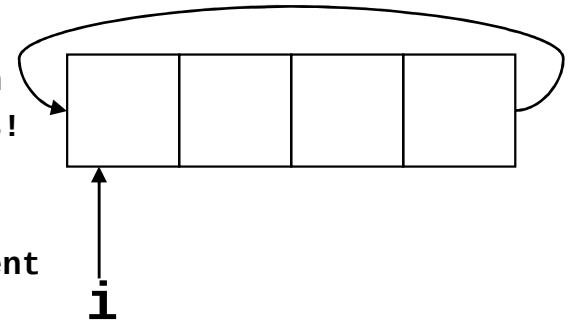

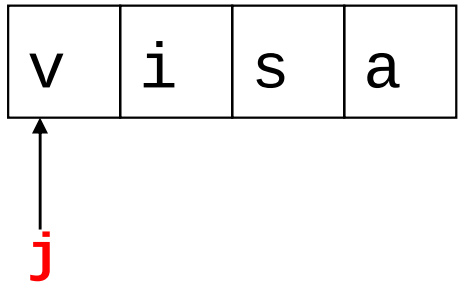

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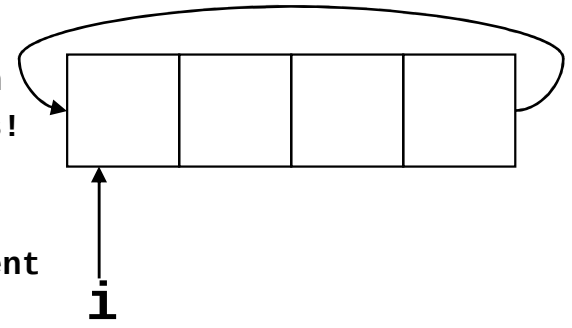

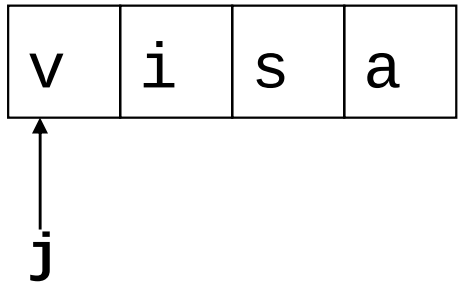

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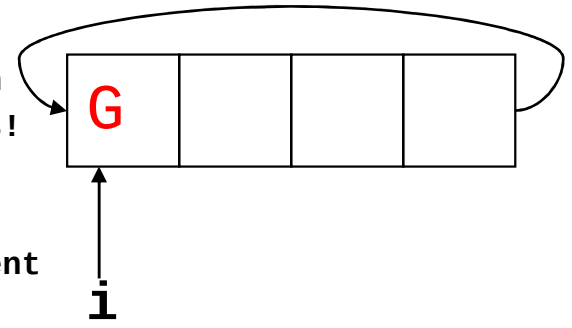

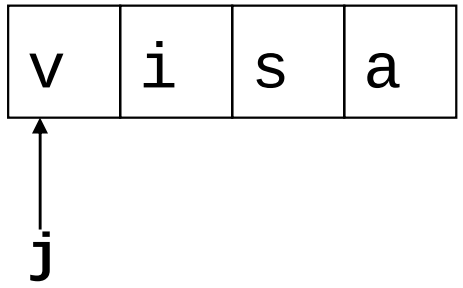

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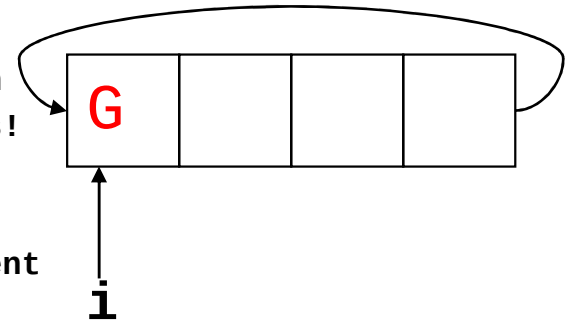
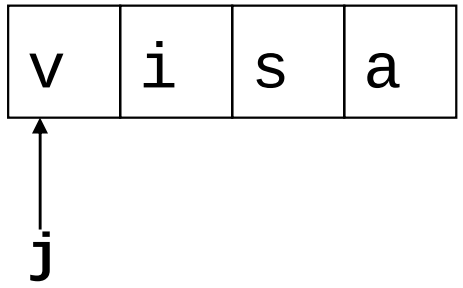
Konversion nach **`bool`** (*false* wenn Eingabe-strom leer)





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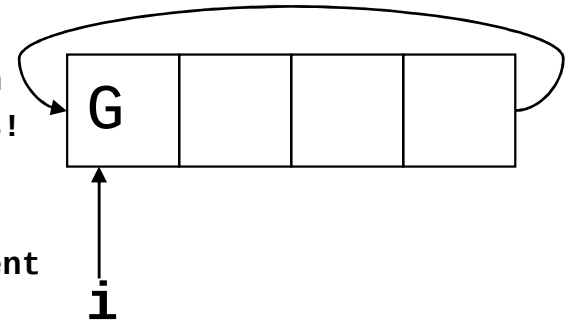
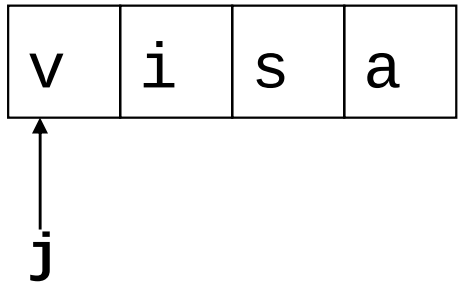
}
```





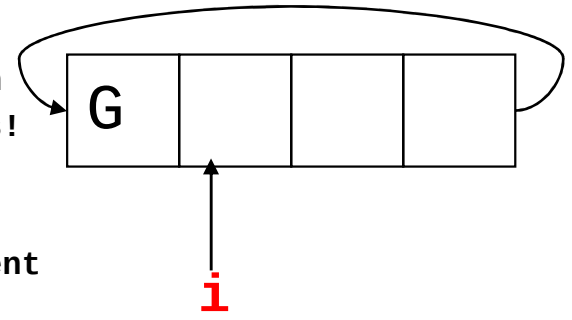
w == 1

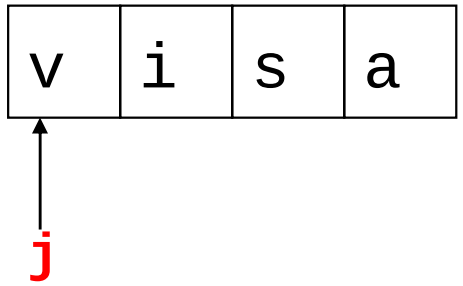
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





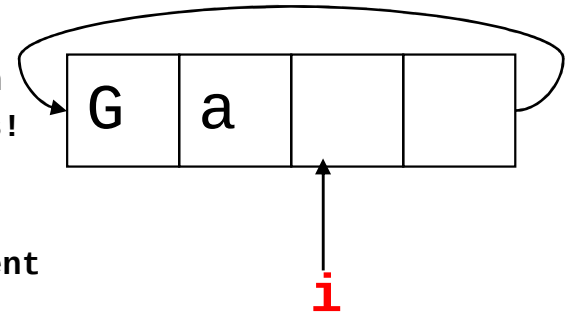
`w == 1`

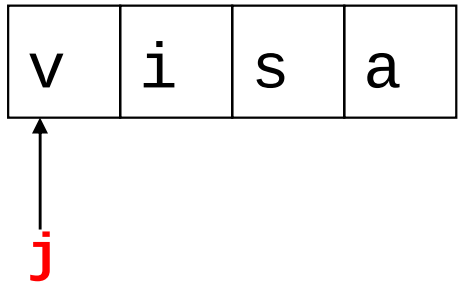
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





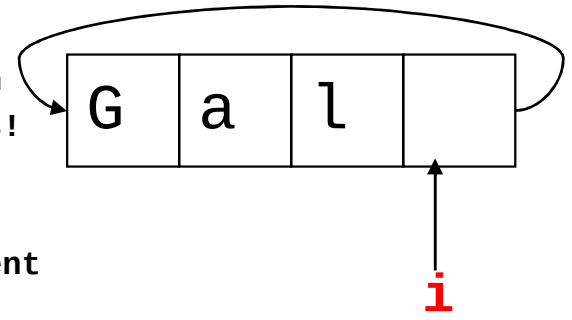
w == 2

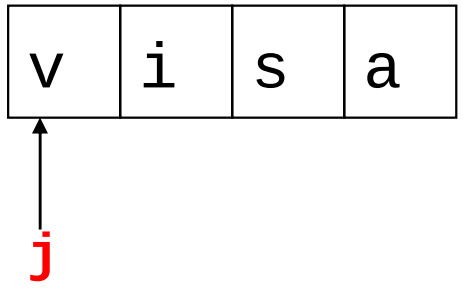
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





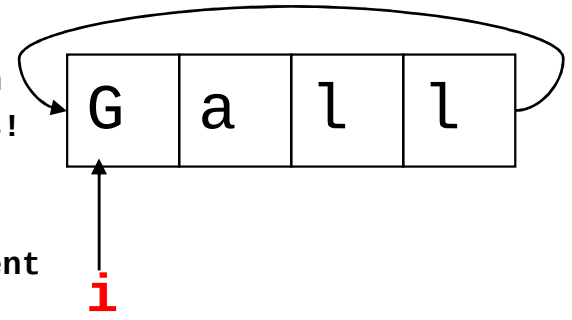
w == 3

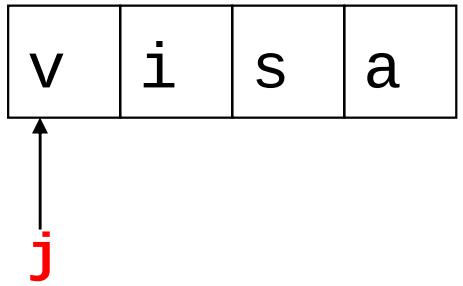
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





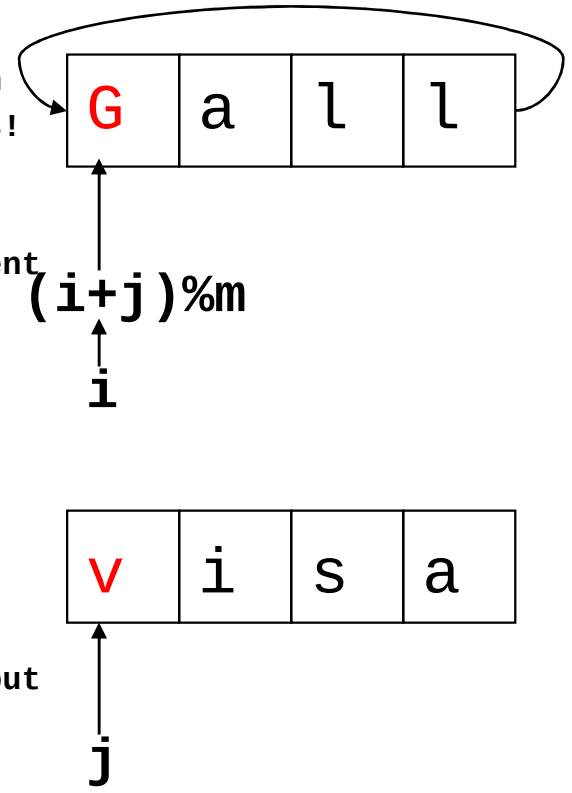
w == 4

Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```

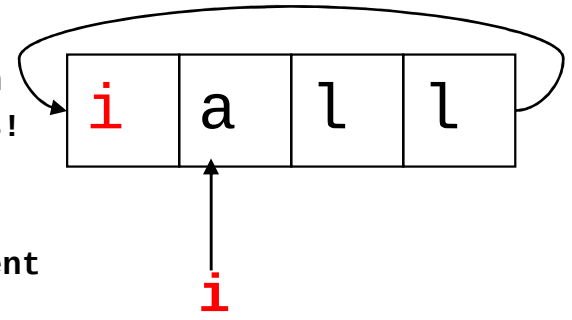


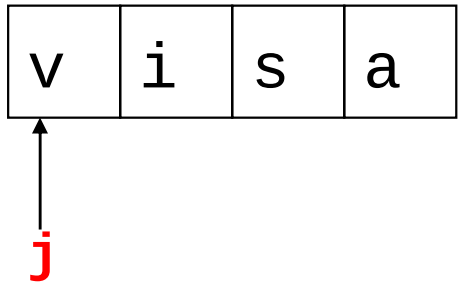
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





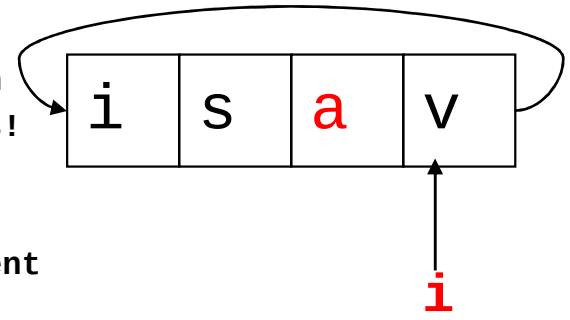
`w == 5`

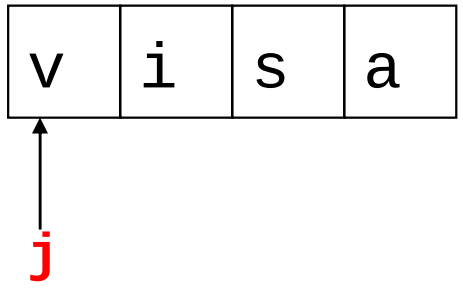
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





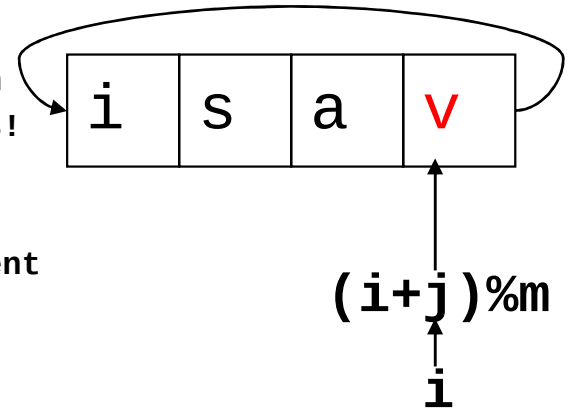
w == 23

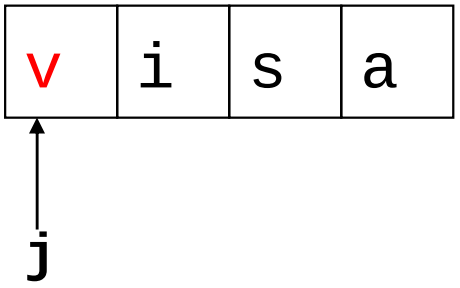
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





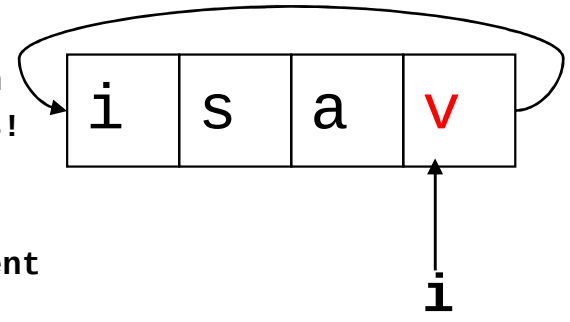
w == 23

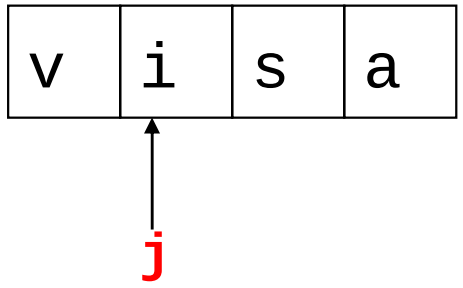
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





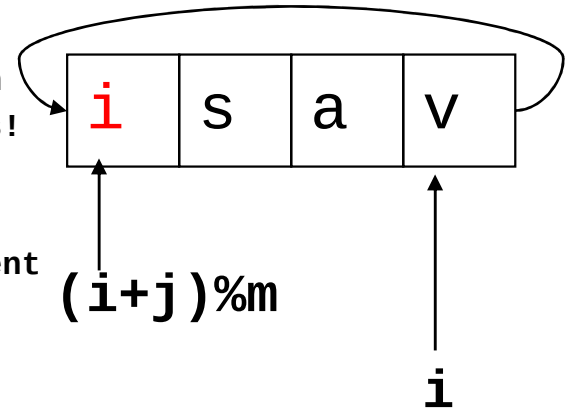
w == 23

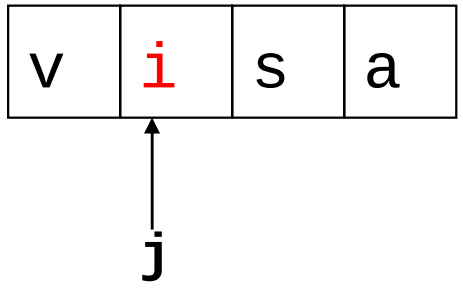
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





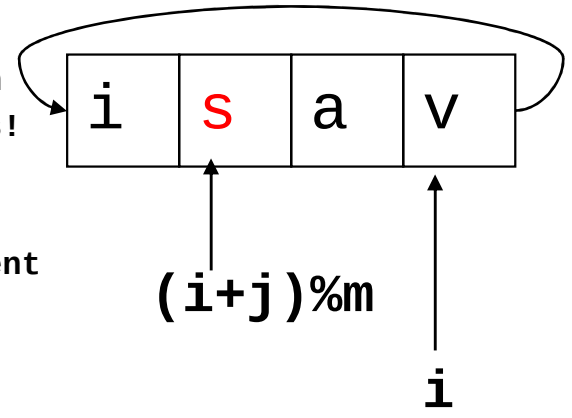
w == 23

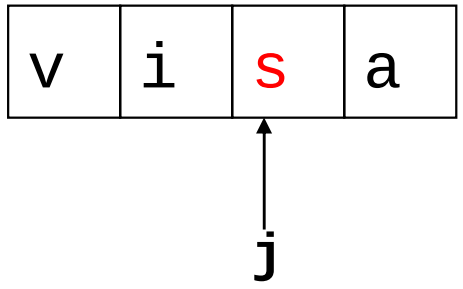
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





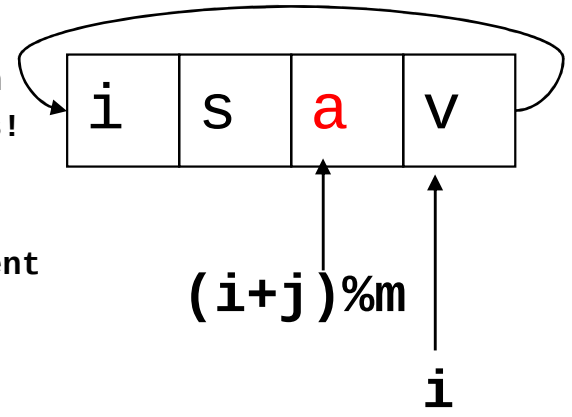
w == 23

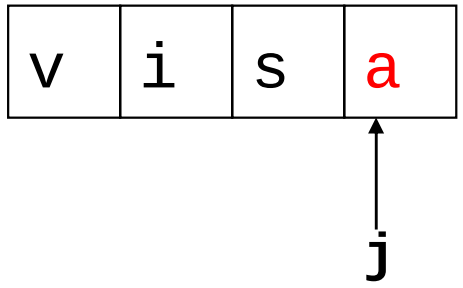
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```





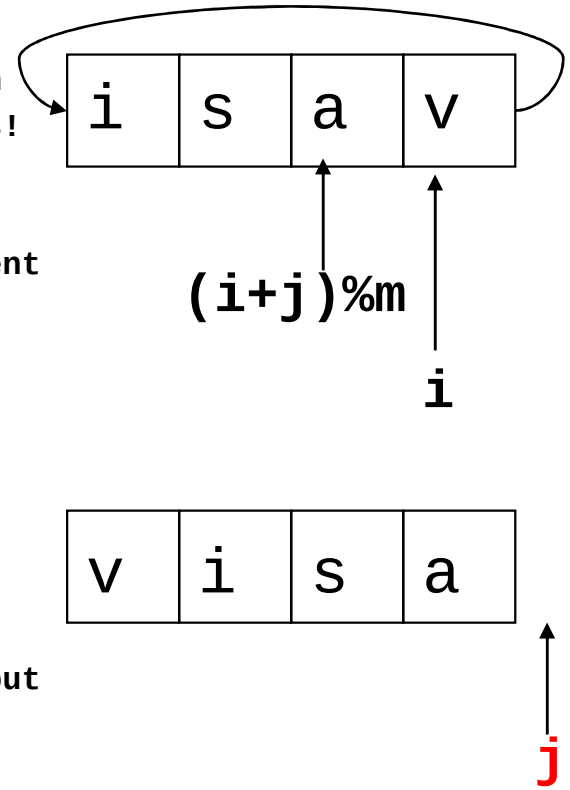
w == 23

Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```



w == 23

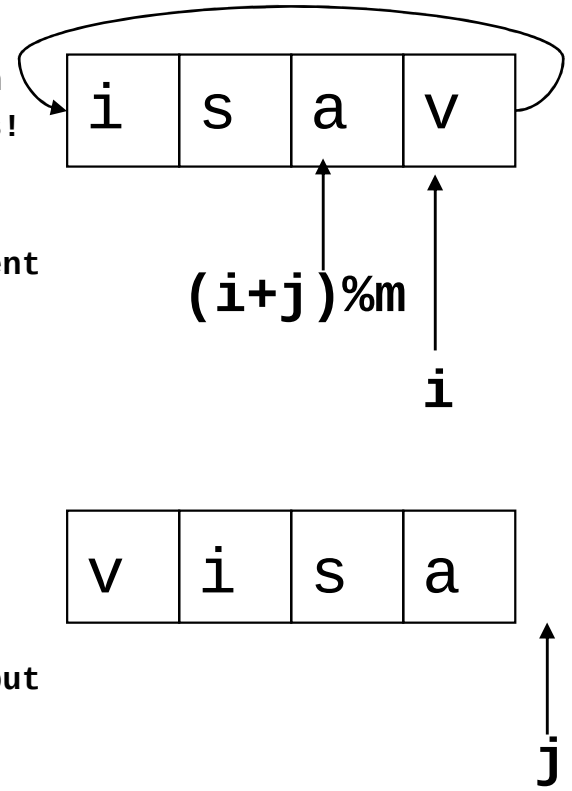
Anwendung: *String matching*

```
  ...
  // find pattern in the text being read from std::cin
  std::cin >> std::noskipws; // don't skip whitespaces!

  for (unsigned int j = 0; j < m;)
    // compare search string with window at j-th element
    if (w < m || s[j] != t[(i+j)%m])
      // input text still too short, or mismatch:
      // advance window by replacing first character
      if (std::cin >> t[i]) {
        std::cout << t[i];
        ++w;           // one more character read
        j = 0;         // restart with first characters
        i = (i+1)%m;   // of string and window
      } else break;    // no more characters in the input
    else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```

false



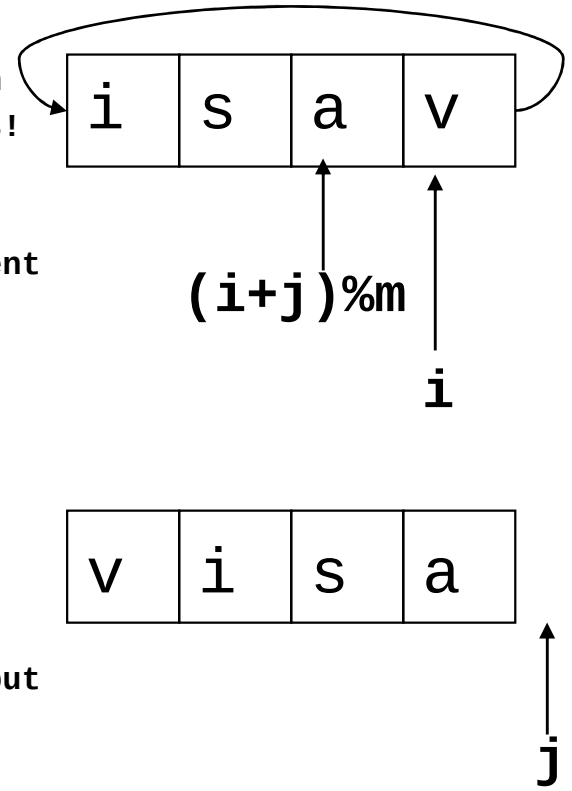
w == 23

Anwendung: *String matching*

```
...
// find pattern in the text being read from std::cin
std::cin >> std::noskipws; // don't skip whitespaces!

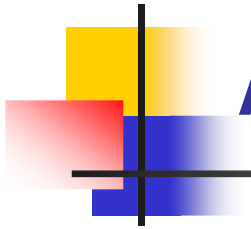
for (unsigned int j = 0; j < m;)
  // compare search string with window at j-th element
  if (w < m || s[j] != t[(i+j)%m])
    // input text still too short, or mismatch:
    // advance window by replacing first character
    if (std::cin >> t[i]) {
      std::cout << t[i];
      ++w;          // one more character read
      j = 0;        // restart with first characters
      i = (i+1)%m;  // of string and window
    } else break;   // no more characters in the input
  else ++j; // match: go to next character

  std::cout << "\n";
  delete[] t;
  return 0;
}
```



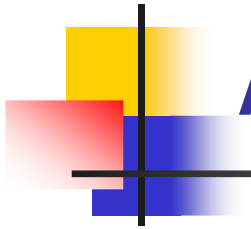
Fertig! Die ersten 23 Text-zeichen wurden ausgegeben

w == 23



Anwendung: *String matching*

```
./string_matching < eratosthenes.cpp
```



Anwendung: *String matching*

- Aufruf des Programms z.B. durch

```
./string_matching < eratosthenes.cpp
```

Eingabe wird nicht von der Tastatur, sondern aus der angegebenen Datei genommen (Umlenkung der Eingabe)

Anwendung: *String matching*

- Aufruf des Programms z.B. durch

```
./string_matching < eratosthenes.cpp
```

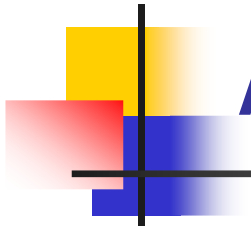
- Ausgabe:

```
// Program: eratosthenes.cpp
// Calculate prime numbers in {2,...,n-1} using
// Eratosthenes' sieve.

#include <iostream>

int main()
{
  const unsigned int n = 1000;

  // definition and initialization: provides us with
  // Booleans crossed_out[0],..., crossed_out[n-1]
  bool
```

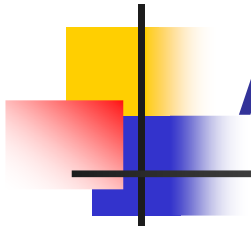


Anwendung: *String matching*

- Aufruf des Programms z.B. durch

```
./string_matching < eratosthenes.cpp
> match.out
```

Ausgabe wird nicht auf den Bildschirm geschrieben, sondern in die angegebene Datei (Umlenkung der Ausgabe)



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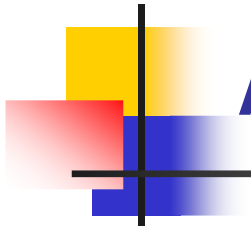

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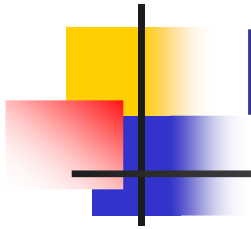
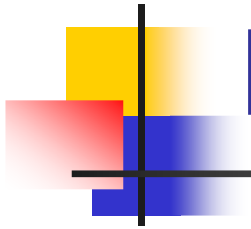
- *Knuth-Morris-Pratt*-Algorithmus ist immer schnell



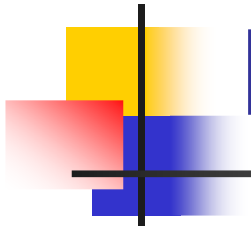
Mehrdimensionale Felder

- sind Felder von Feldern



Mehrdimensionale Felder

- sind Felder von Feldern
- dienen zum Speichern von *Tabellen*, *Matrizen*,...



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int a[2][3]
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a hat zwei Elemente, und jedes von ihnen ist ein Feld der Länge 3 mit zugrundeliegendem Typ **int**

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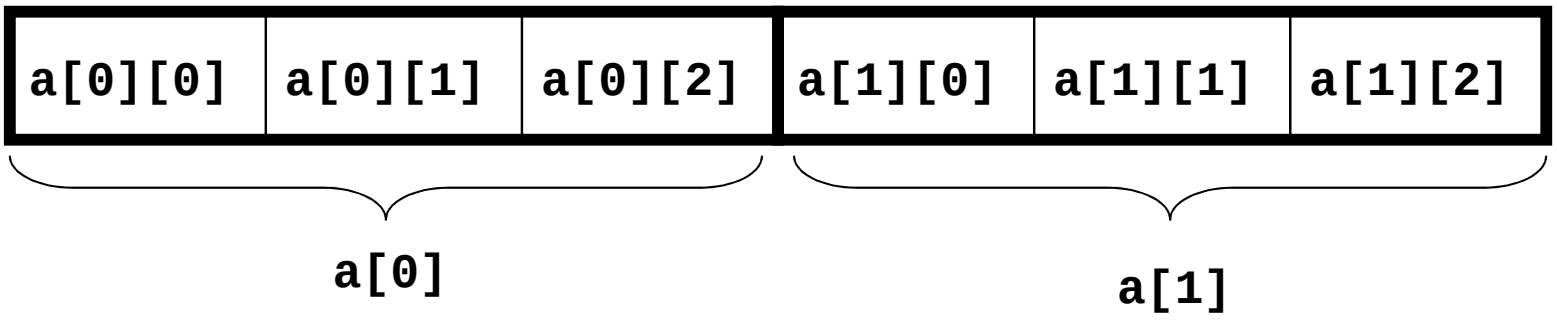
Im Speicher: *flach*



Mehrdimensionale Felder

- sind Felder von Feldern

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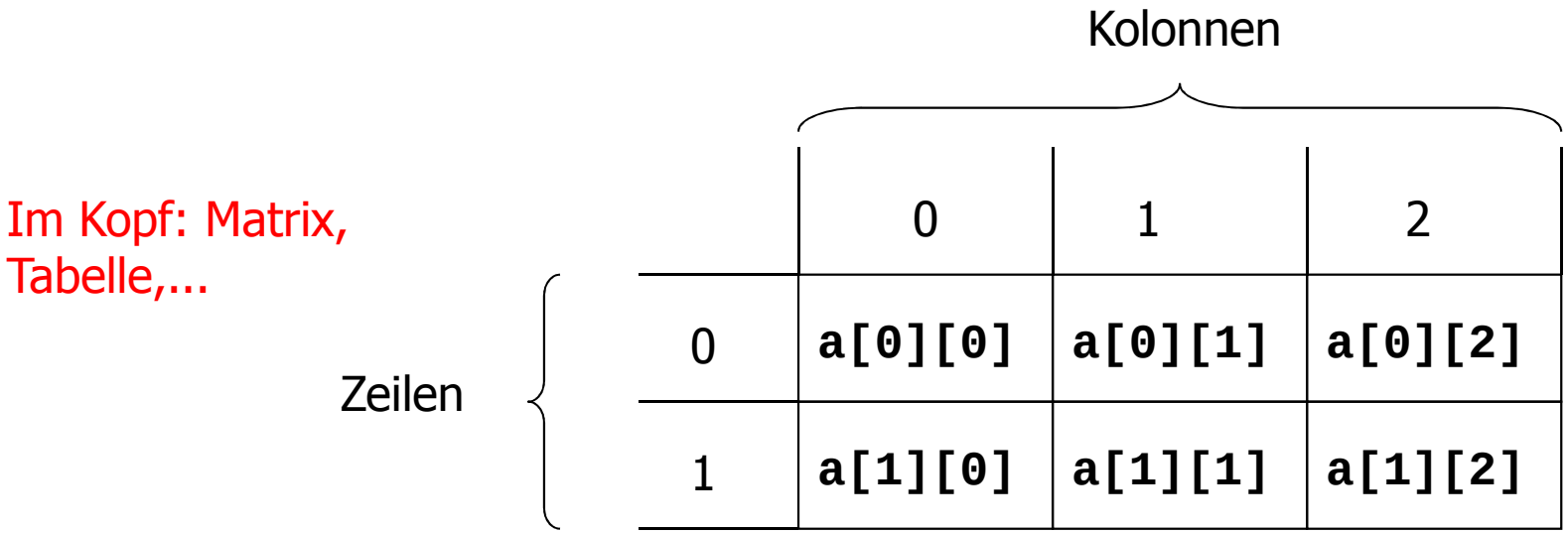
```

Im Kopf: Matrix, Tabelle,...



Mehrdimensionale Felder

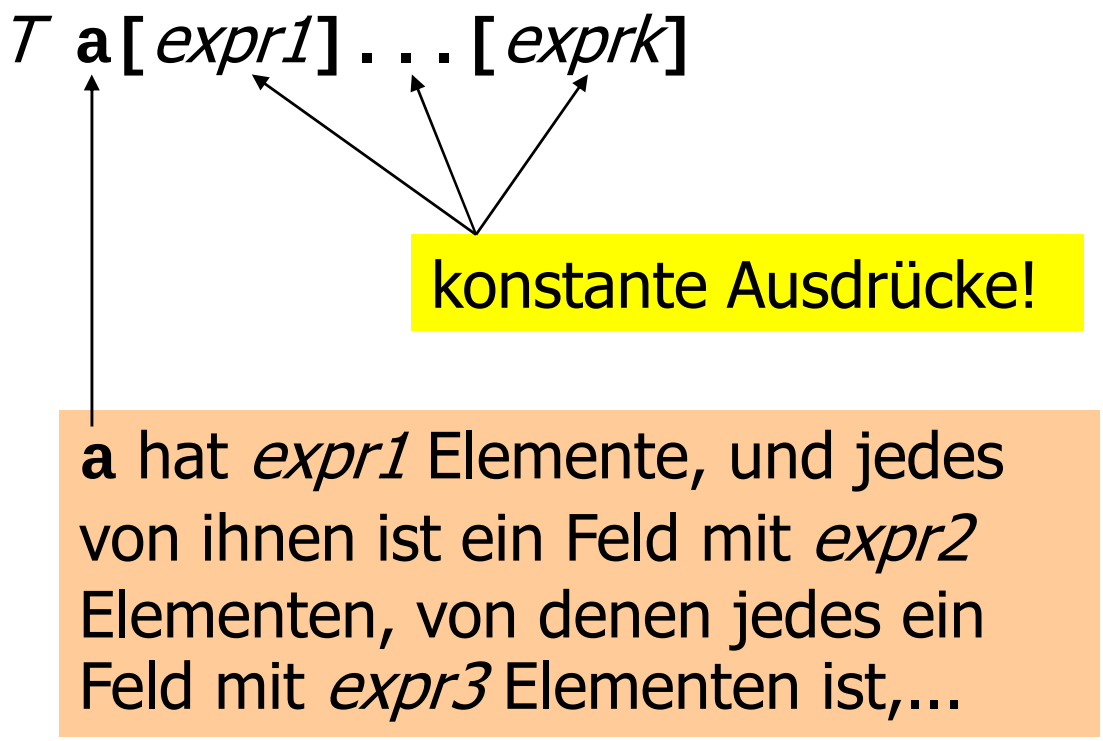
- sind Felder von Feldern von Feldern...

T **a**[*expr1*]...[*exprk*]

a hat *expr1* Elemente, und jedes von ihnen ist ein Feld mit *expr2* Elementen, von denen jedes ein Feld mit *expr3* Elementen ist,...

Mehrdimensionale Felder

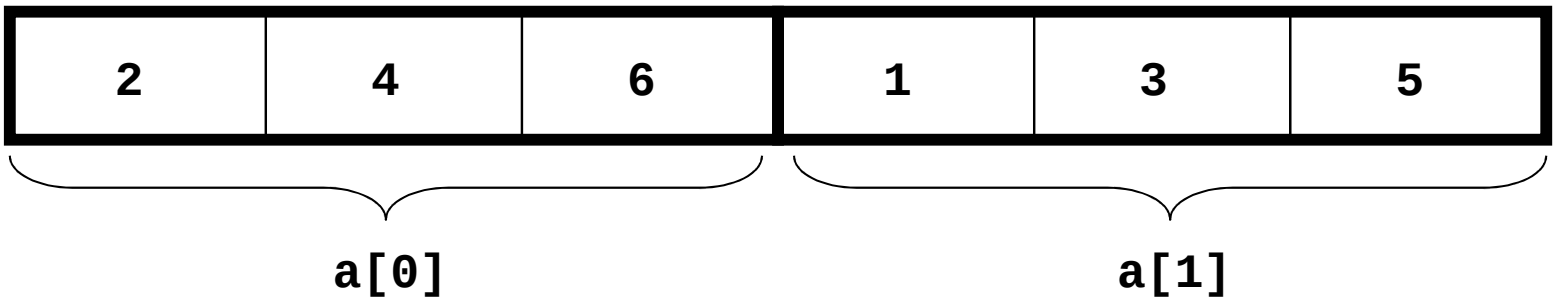
- sind Felder von Feldern von Feldern...



Mehrdimensionale Felder

Initialisierung:

```
int a[2][3] =
{
 {2,4,6}, {1,3,5}
}
```



Mehrdimensionale Felder

Initialisierung:

erste Dimension kann weggelassen werden

```
int a[][3] =
{
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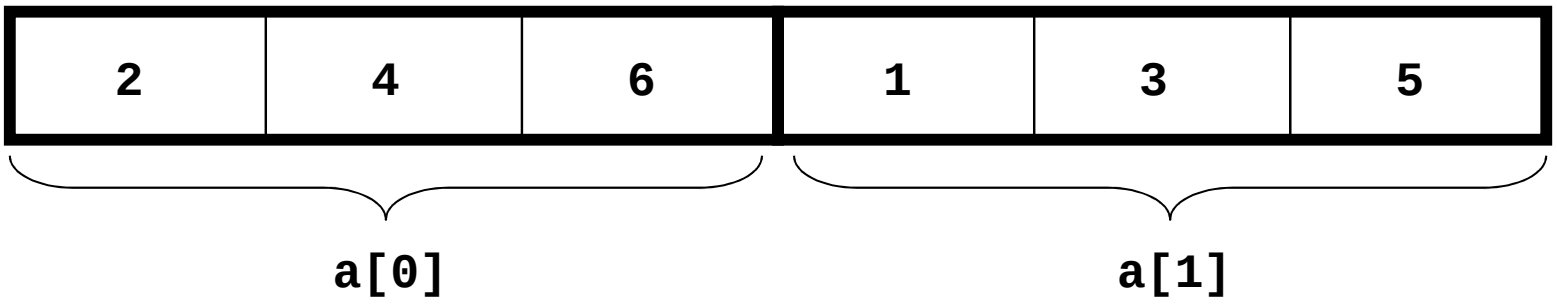
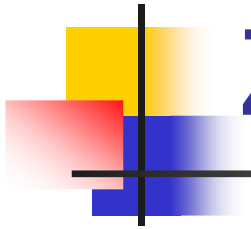
```





Zeiger auf Felder

Wie iteriert man natürlich über ein mehr-dimensionales Feld?

Zeiger auf Felder

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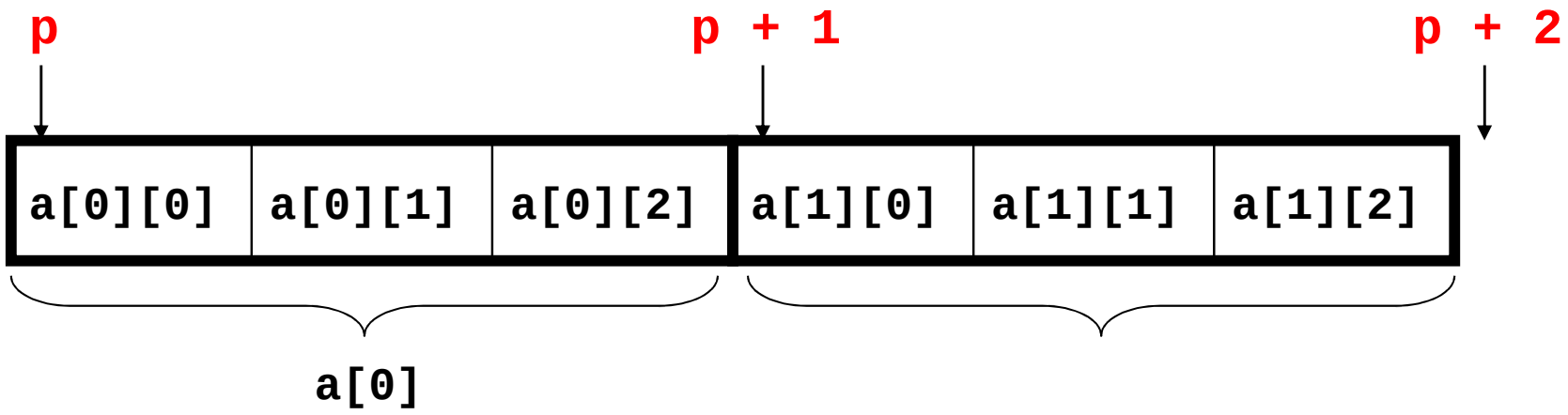
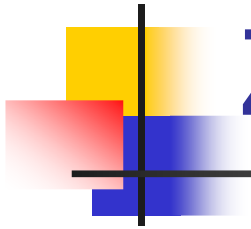
```
int a[2][3];
int (*p)[3] = a; // Zeiger auf erstes Element
```





Zeiger auf Felder

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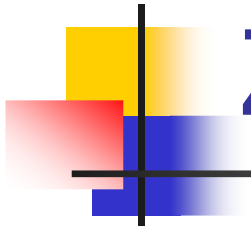
```
int a[2][3];
int (*p)[3] = a; // Zeiger auf erstes Element
```

Implizite Typdefinition: **`*p`** ist vom Typ **`int[3]`**, also ist **`p`** ein Zeiger auf **`int[3]`**



Zeiger auf Felder

Wie iteriert man natürlich über ein mehr-dimensionales Feld?

```
int a[2][3];
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```

Ohne Klammern: **p** ist ein Feld von 3 Zeigern auf **int**

```
int *p [3]; // int* p[3]
```

Zeiger auf Felder

Wie iteriert man natürlich über ein[illegible]-dimensionales Feld?

```
int a[2][3];
int (*p)[3] = a; //                    erstes Element
```

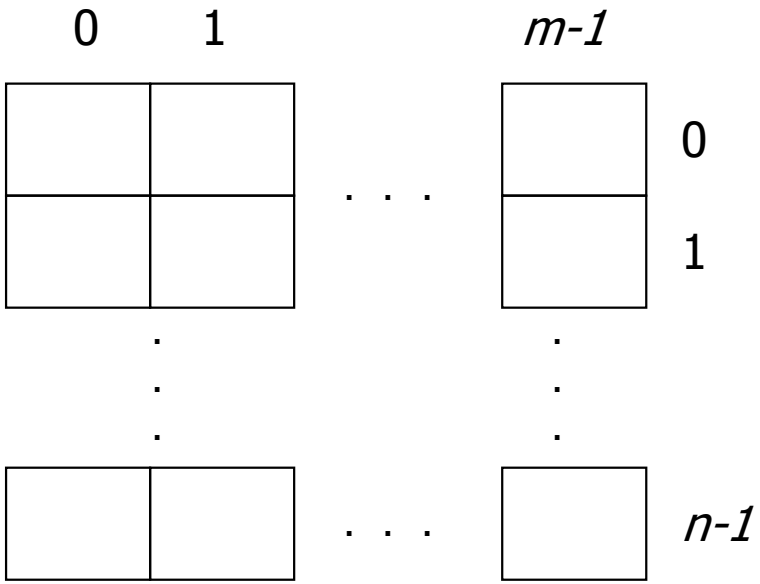
Ohne Klar[illegible]eld von 3 Zeigern auf **int**

```
[illegible] int* p[3]
```

Solche Syntax-"Gemeinheiten" muss man nicht sich nicht merken, nur bei Bedarf nachschauen (Skript)!

Felder von Zeigern

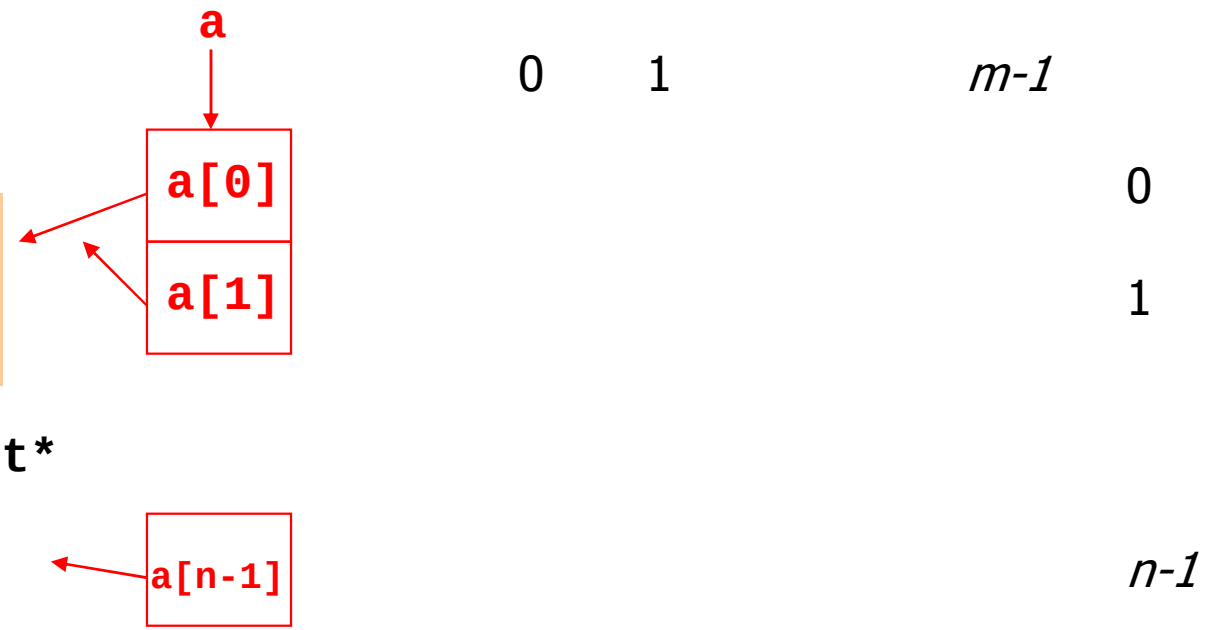
- Wie bekommen wir mehrdimensionale Felder mit variablen Dimensionen?



Felder von Zeigern

- Wie bekommen wir mehrdimensionale Felder mit variablen Dimensionen?

```
int** a = new int*[n];
```



a ist Zeiger auf das erste Element eines Feldes von *n* Zeigern auf **`int`**

zugrundeliegender Typ: **`int*`**

Felder von Zeigern

- Wie bekommen wir mehrdimensionale Felder mit variablen Dimensionen?

```
int** a = new int*[n];
for (int i = 0; i < n; ++i)
  a[i] = new int[m];
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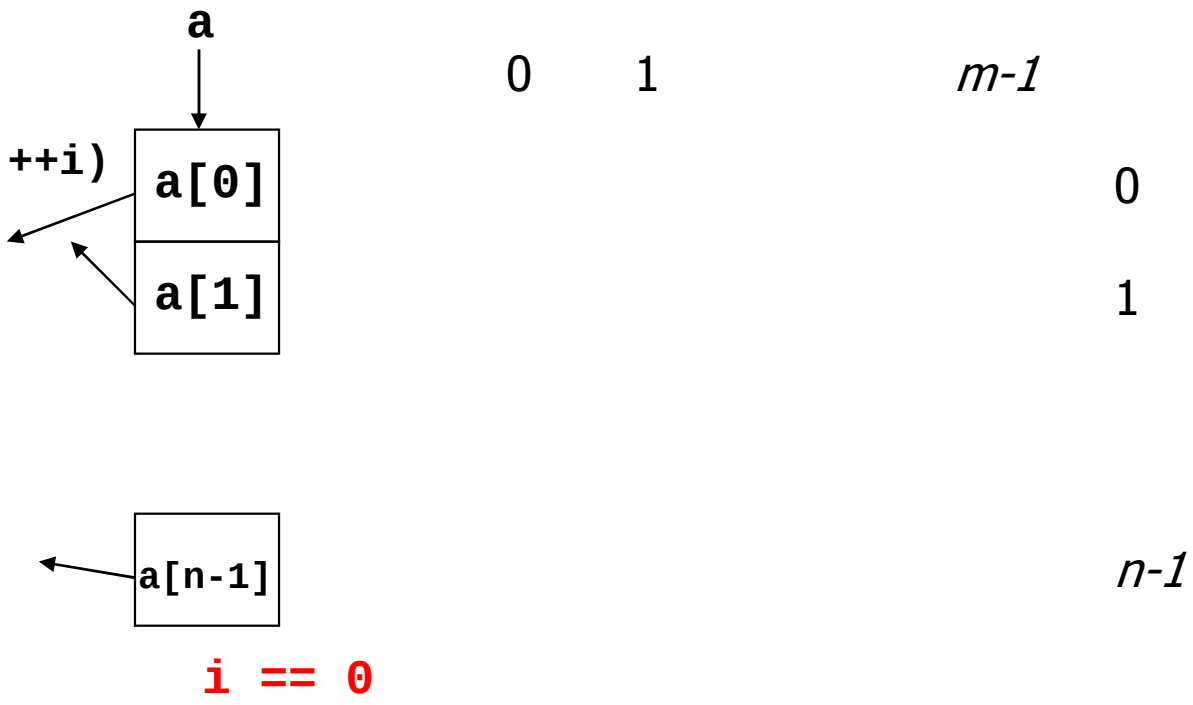

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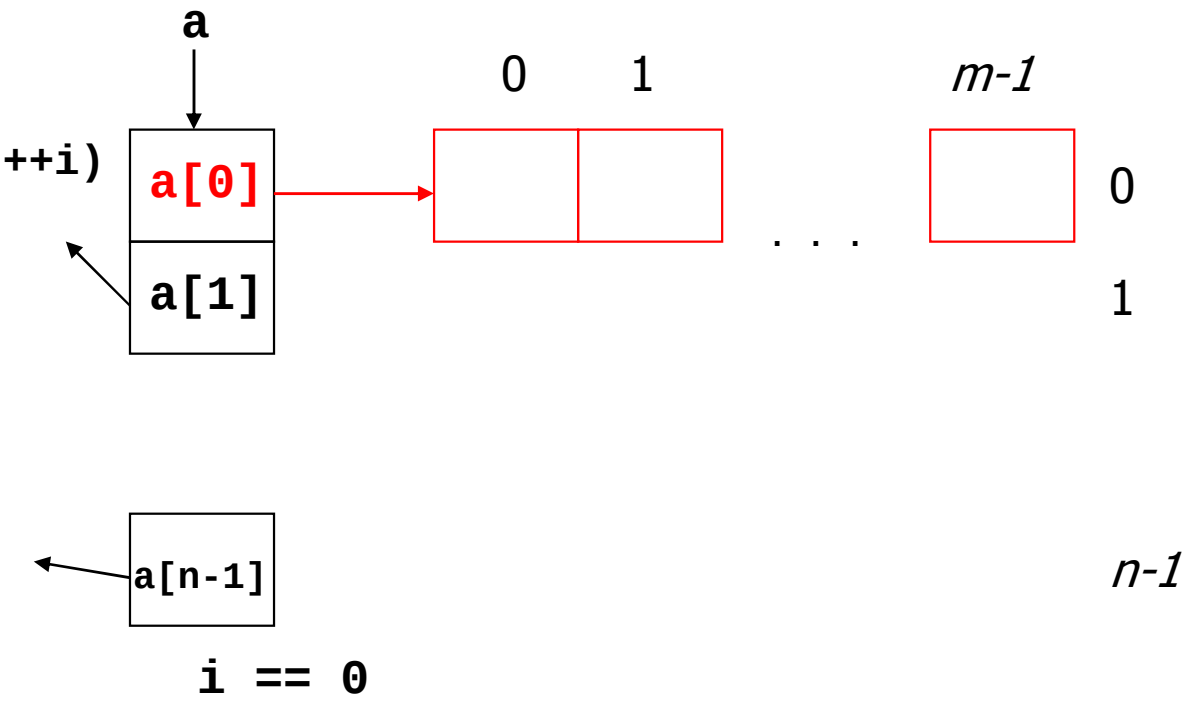

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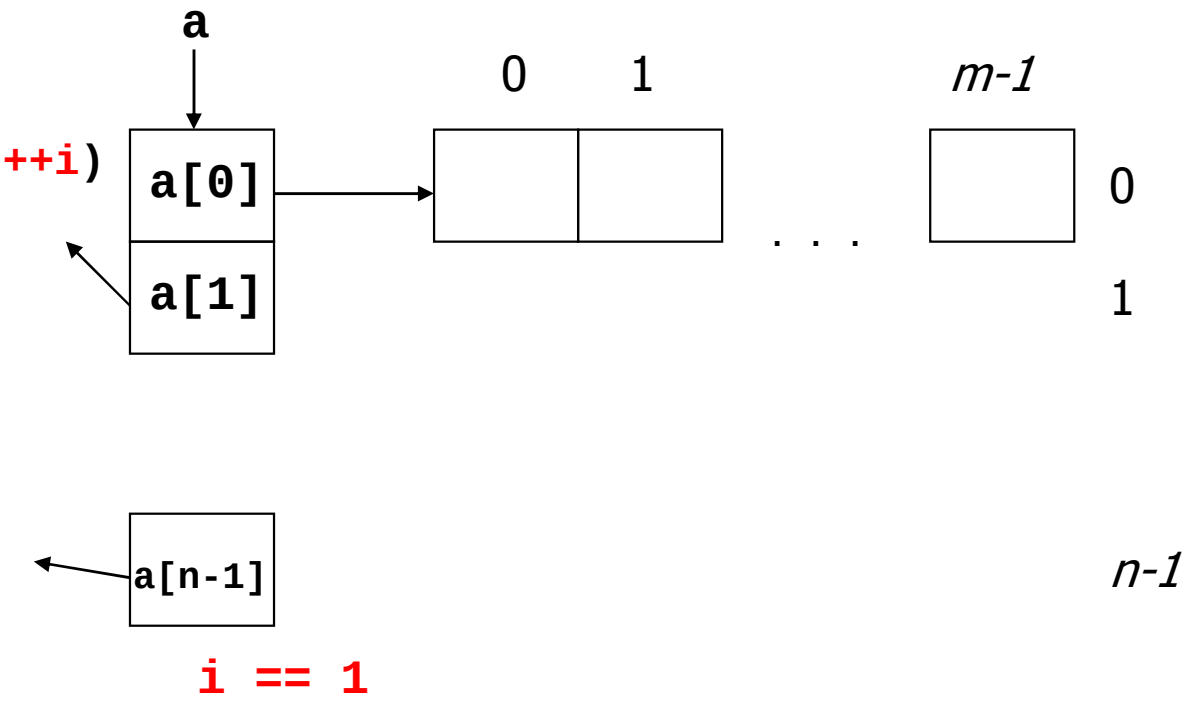

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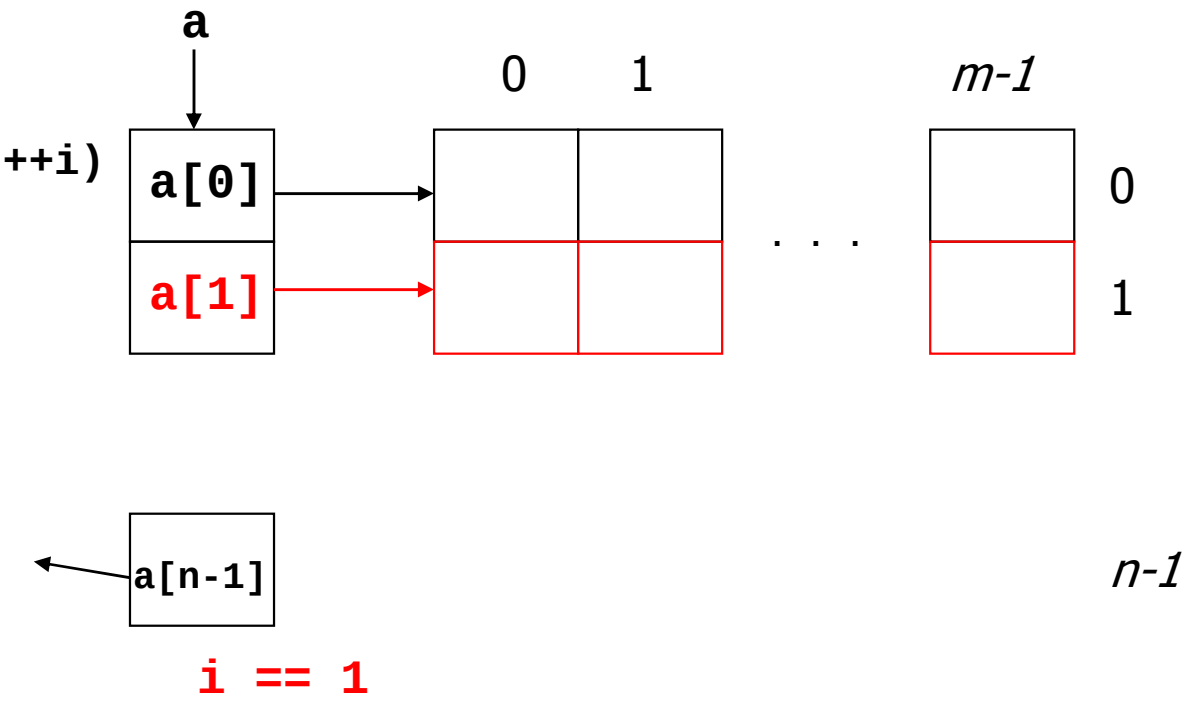


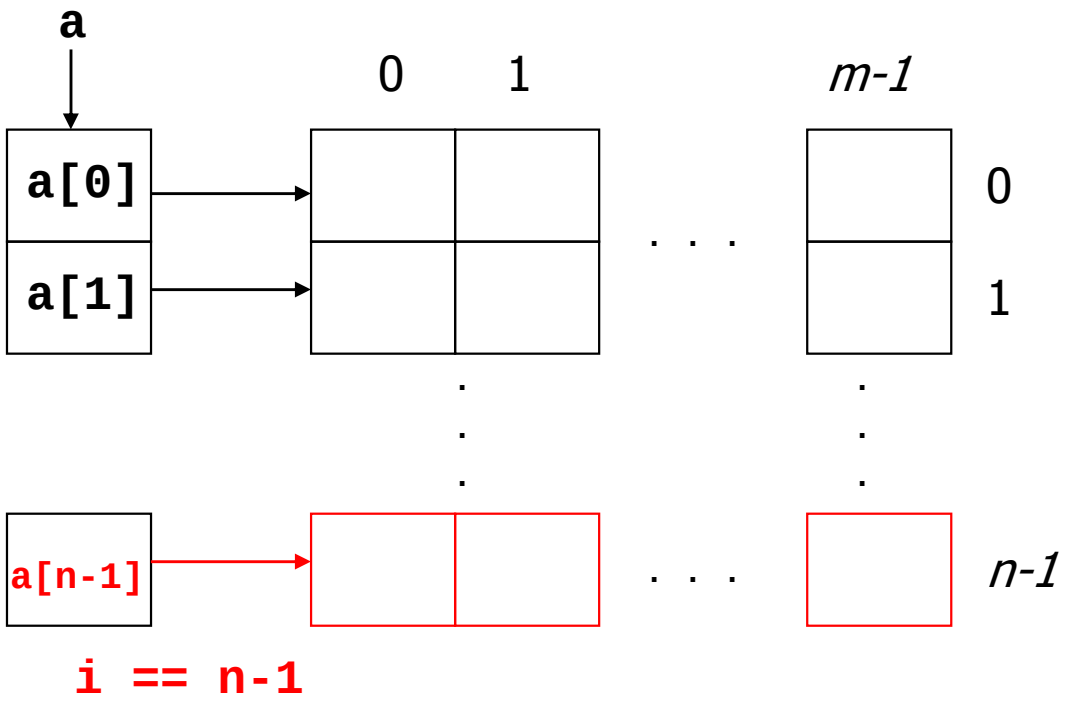
a[1] ist Zeiger auf das erste Element eines Feldes von *m* **int**'s

Felder von Zeigern

- Wie bekommen wir mehrdimensionale Felder mit variablen Dimensionen?

```
int** a = new int*[n];
for (int i = 0; i < n; ++i)
  a[i] = new int[m];
```

a[n-1] ist Zeiger auf das erste Element eines Feldes von *m* **int**'s



Felder von Zeigern

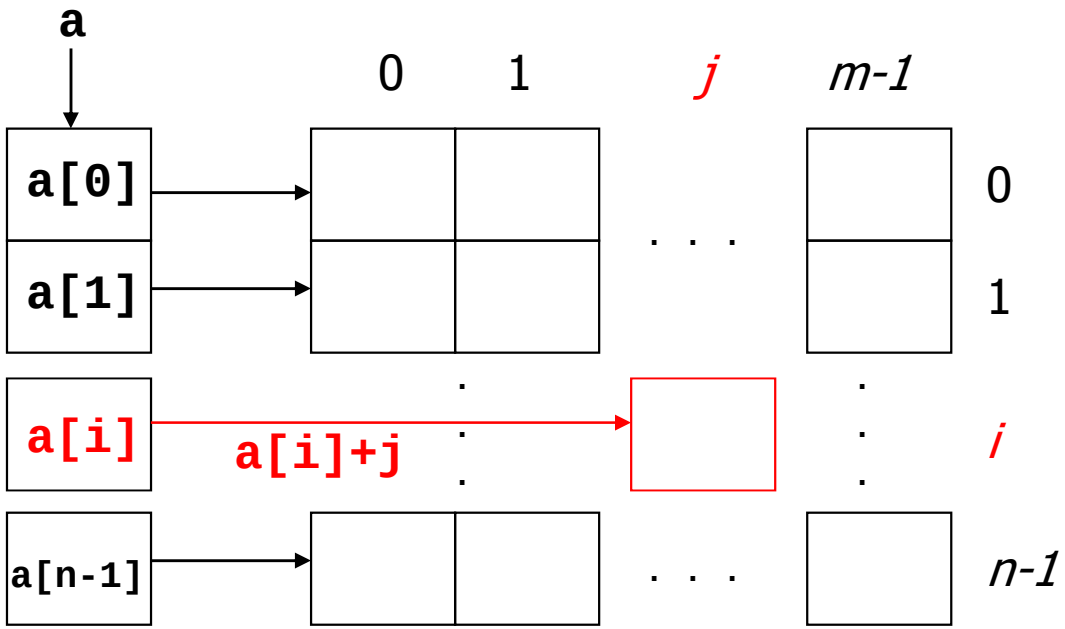
- Wie bekommen wir mehrdimensionale Felder mit variablen Dimensionen?

Wahlfreier Zugriff:

`a[i][j]`

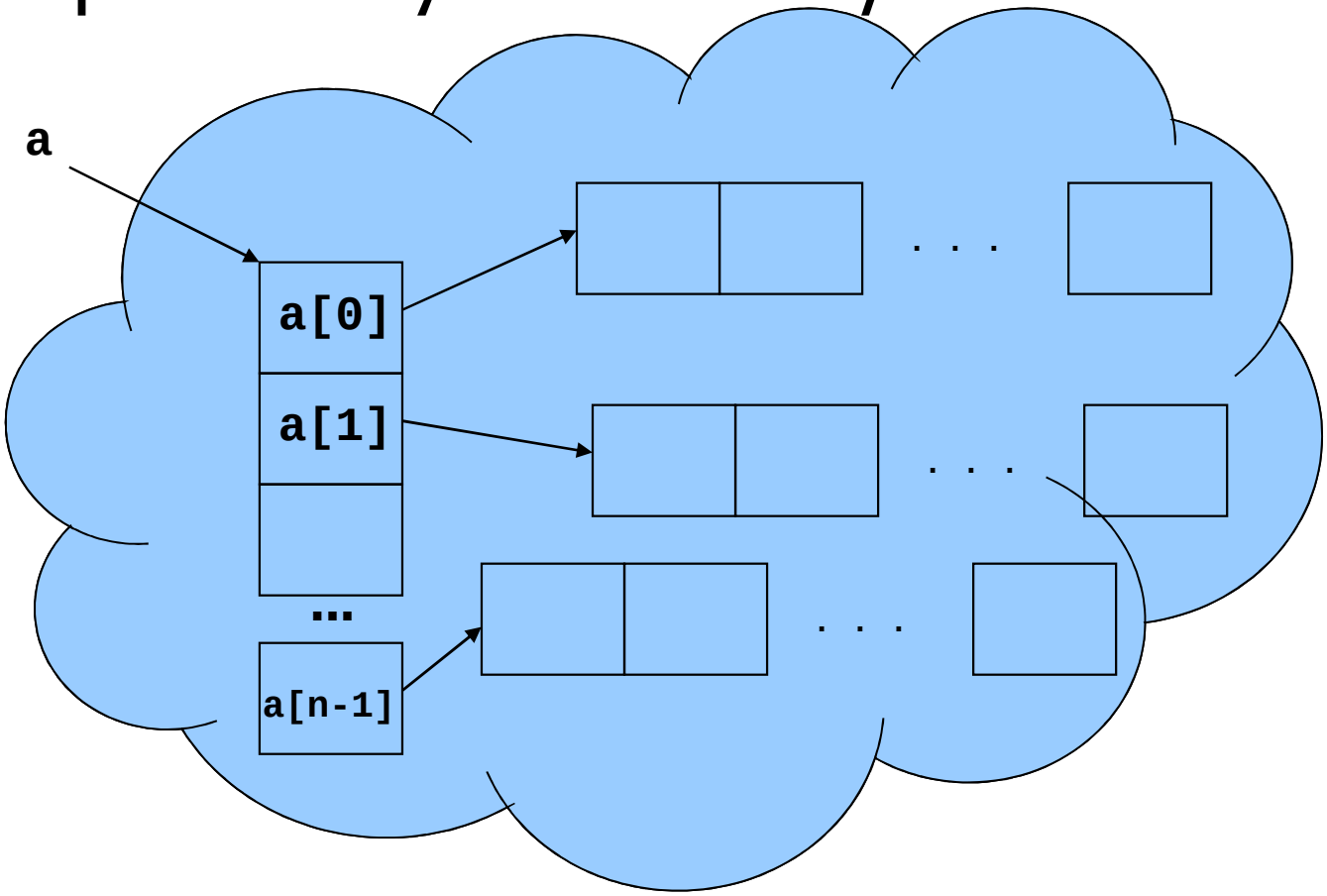
`*(a[i]+j)`

Zeiger



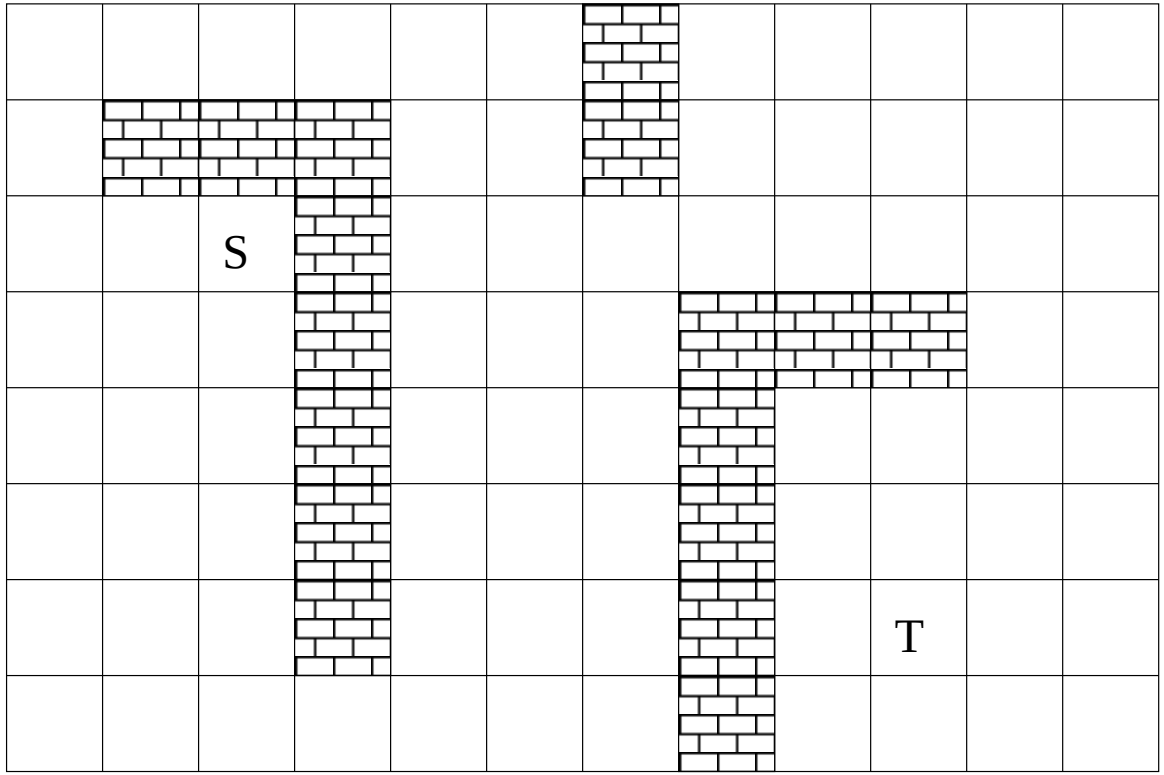
Felder von Zeigern

- Speicherlayout im *Heap* :



Anwendung: kürzeste Wege

Fabrik-Halle ($n \times m$ quadratische Zellen)



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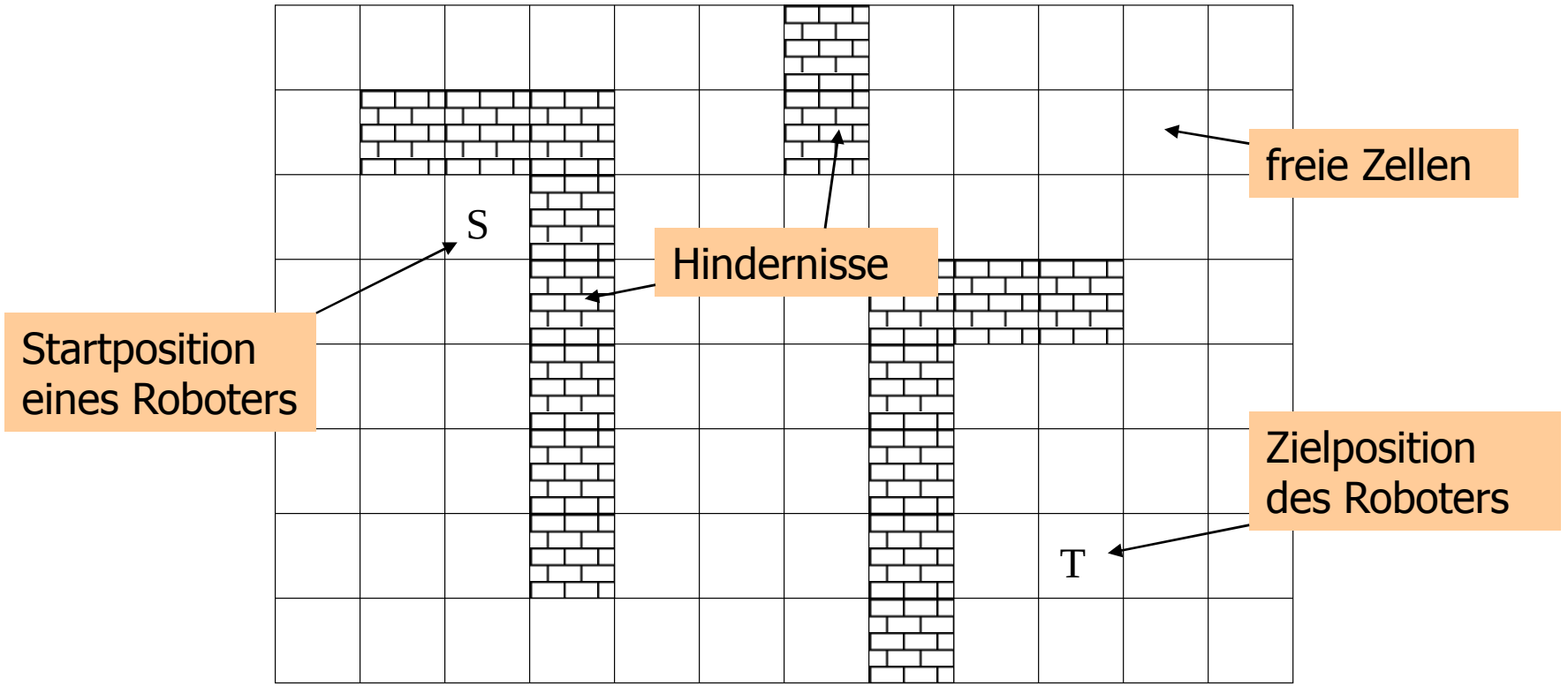

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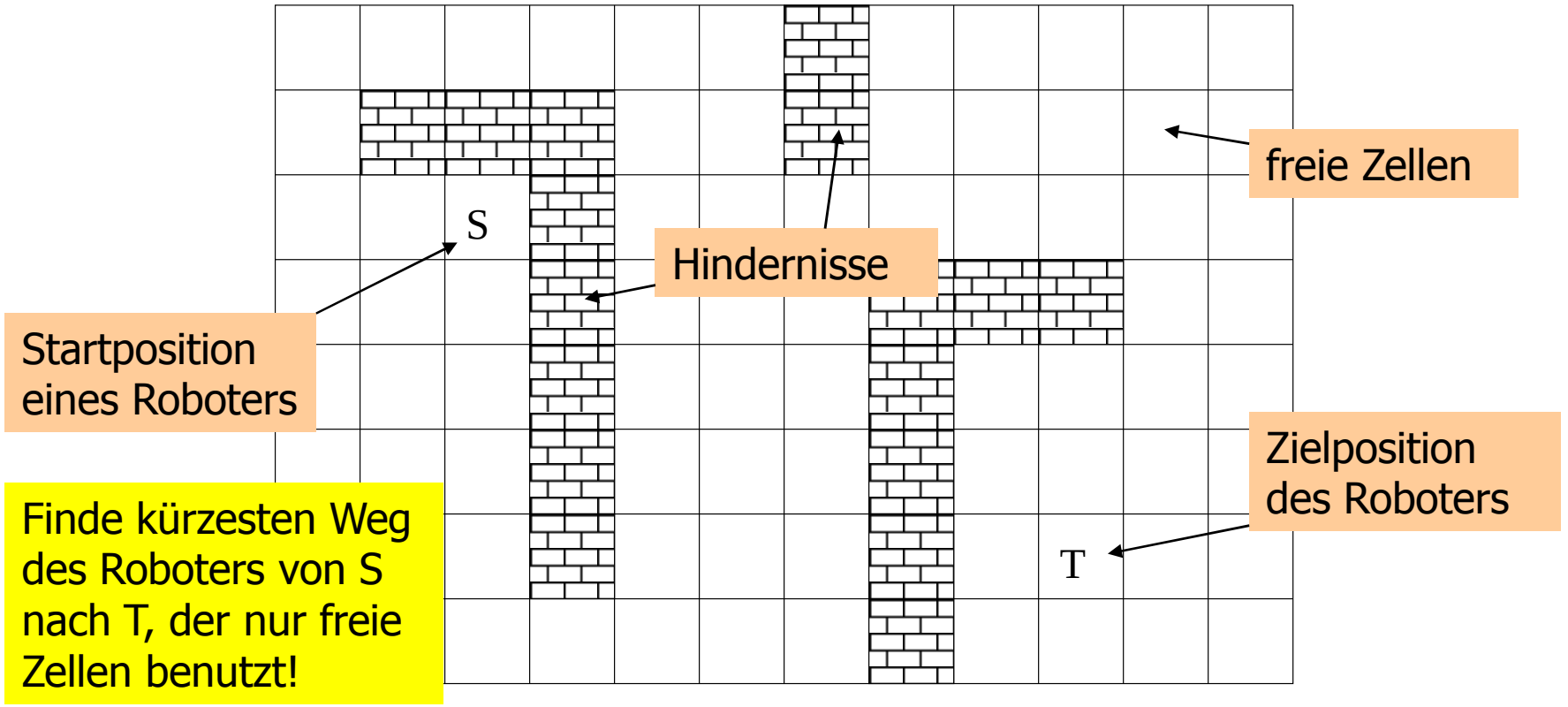

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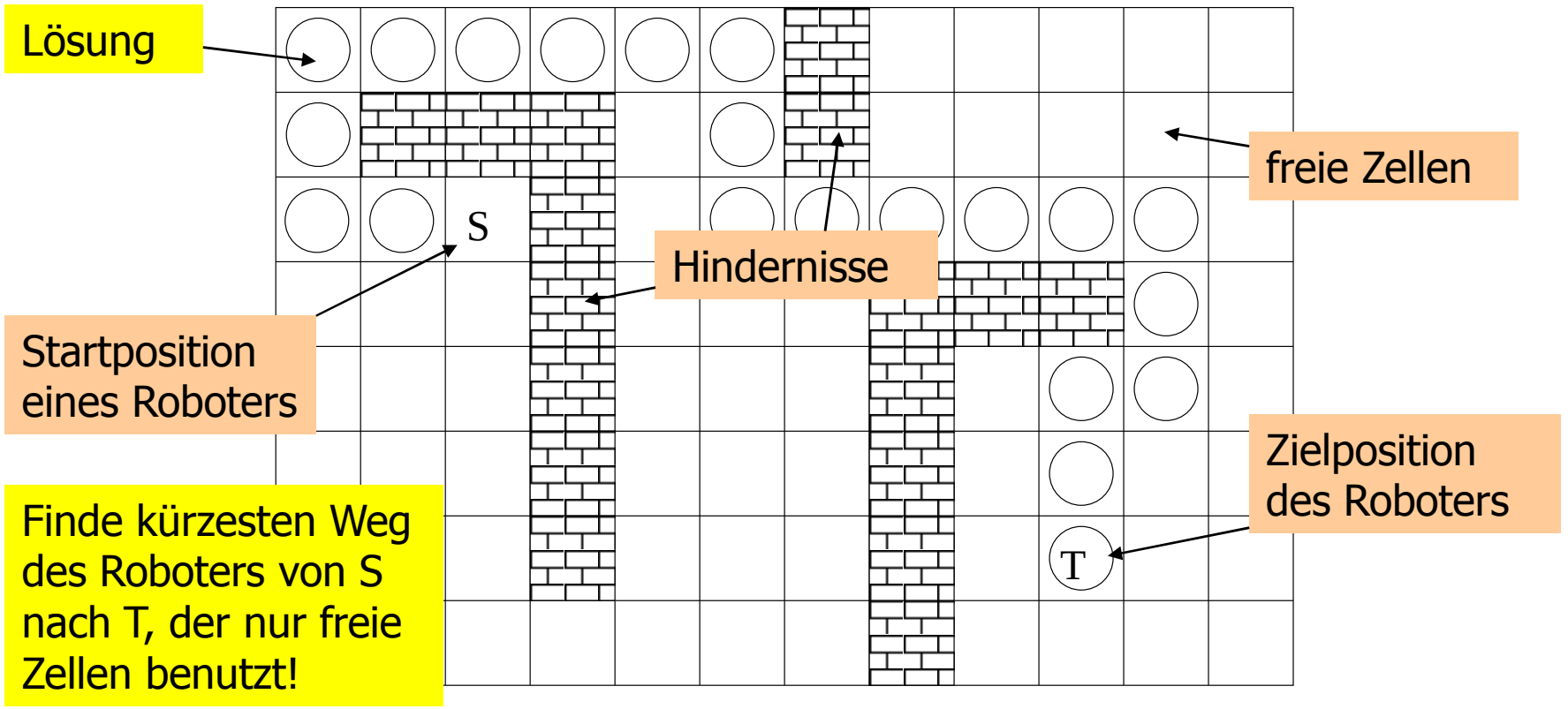
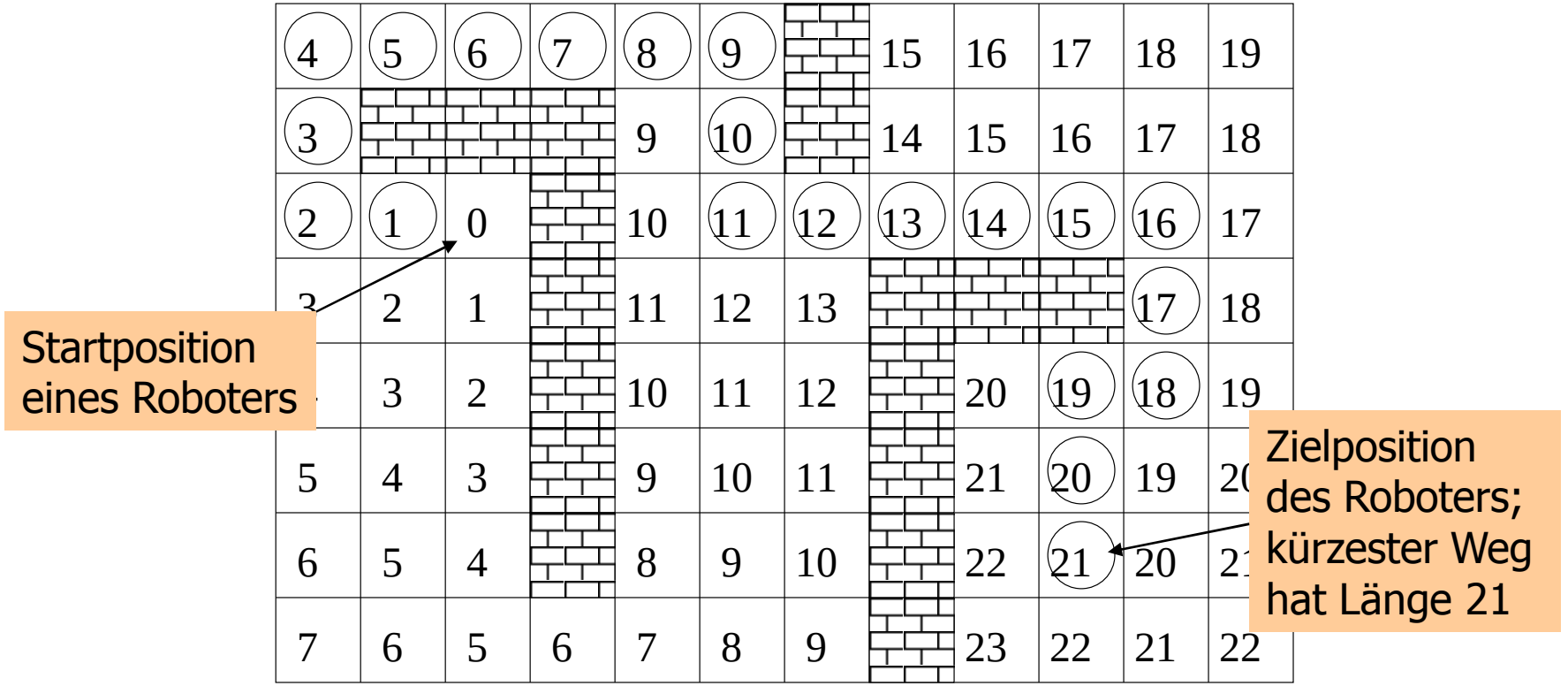


Ein (scheinbar) anderes Problem

Finde die *Längen* der kürzesten Wege zu *allen* möglichen Zielen!



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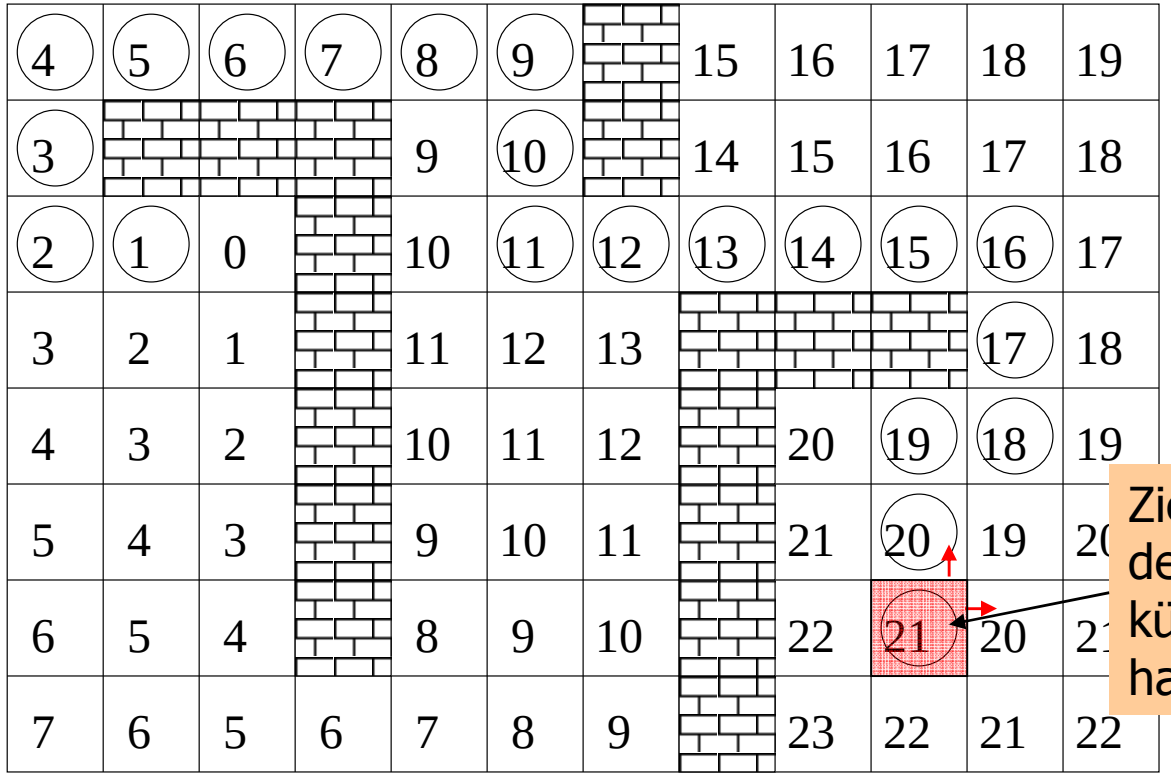
starte in T; folge einem Weg mit (jeweils um eins) *sinkenden* Längen!



Zielposition des Roboters; kürzester Weg hat Länge 21

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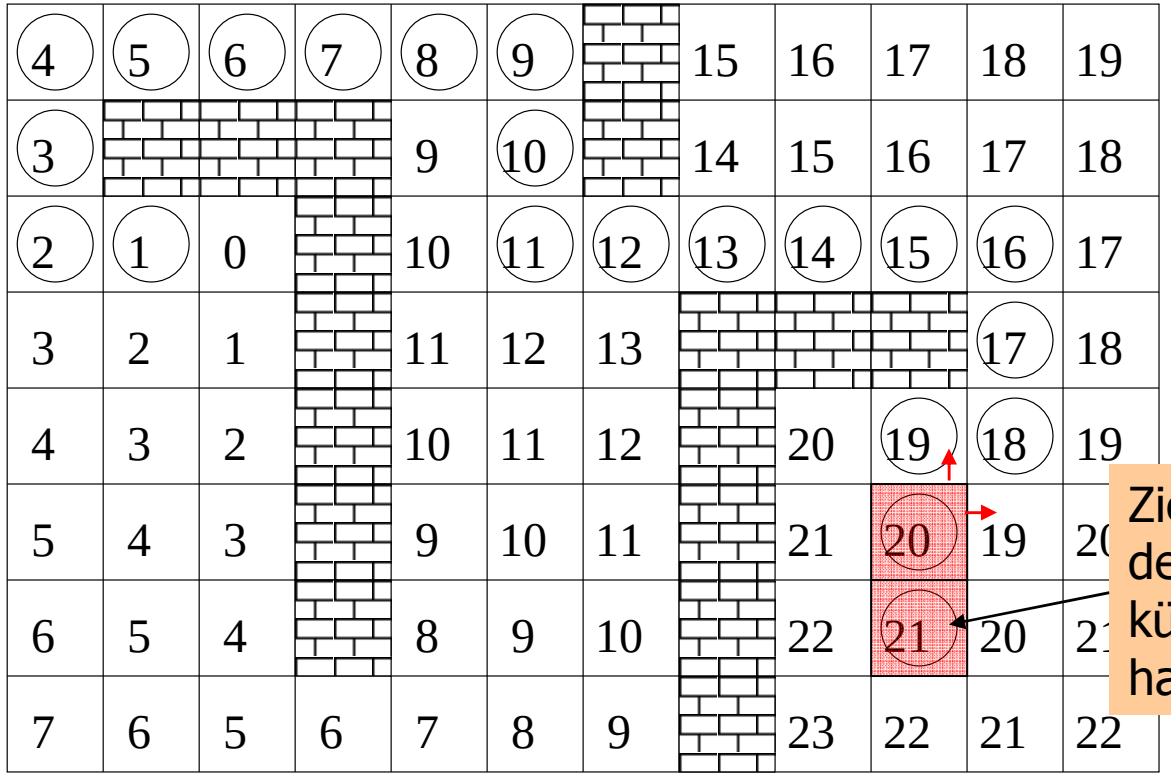

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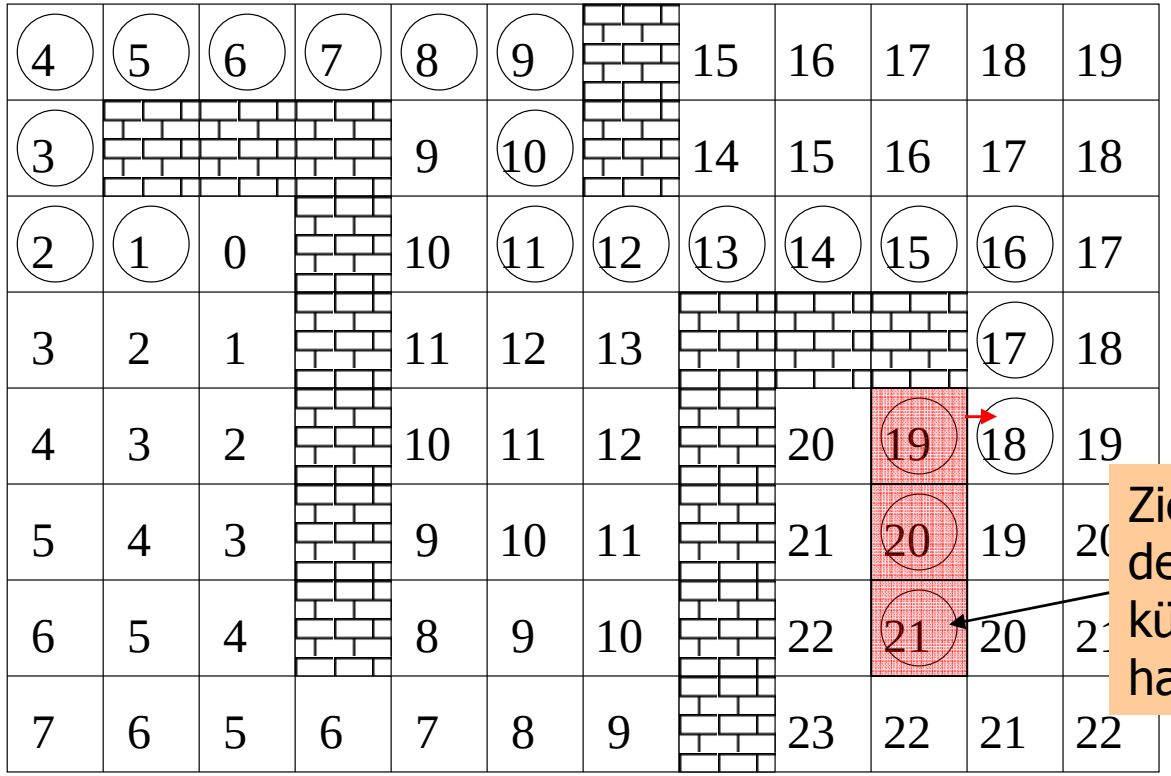

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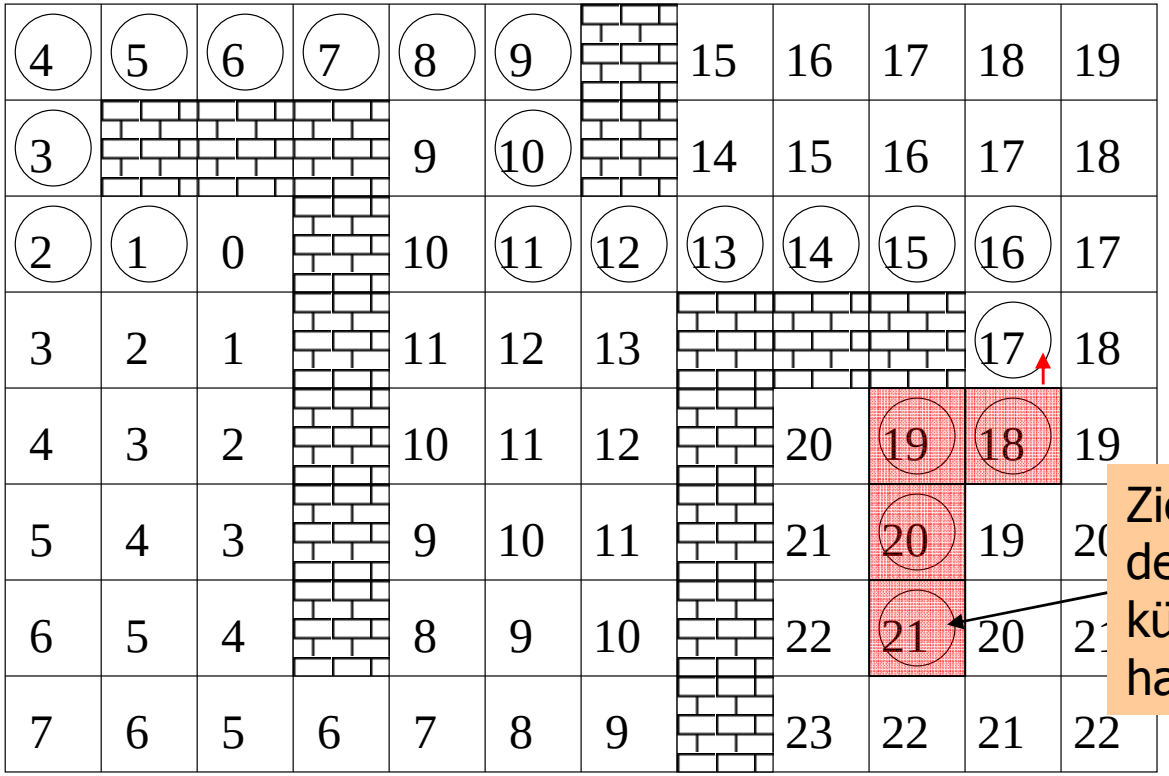

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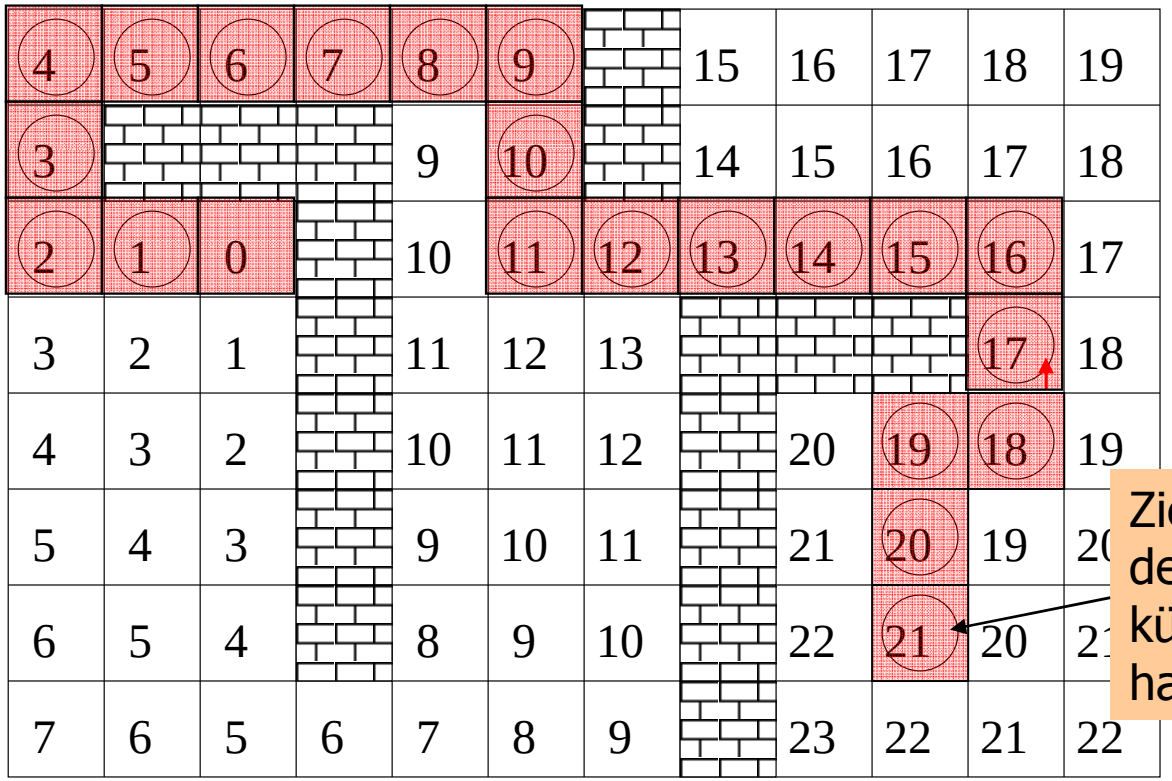
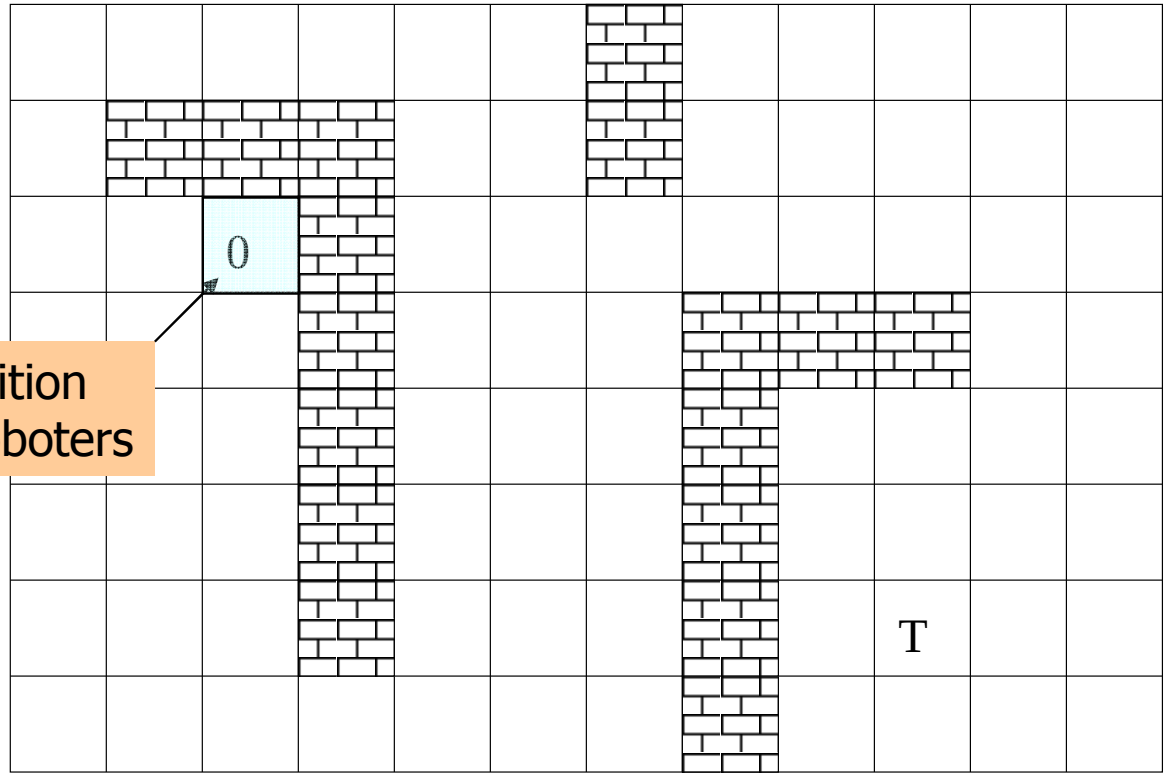
Weglänge 21 (optimal)



Zielposition des Roboters; kürzester Weg hat Länge 21

Markierung aller Zellen mit ihren Weglängen

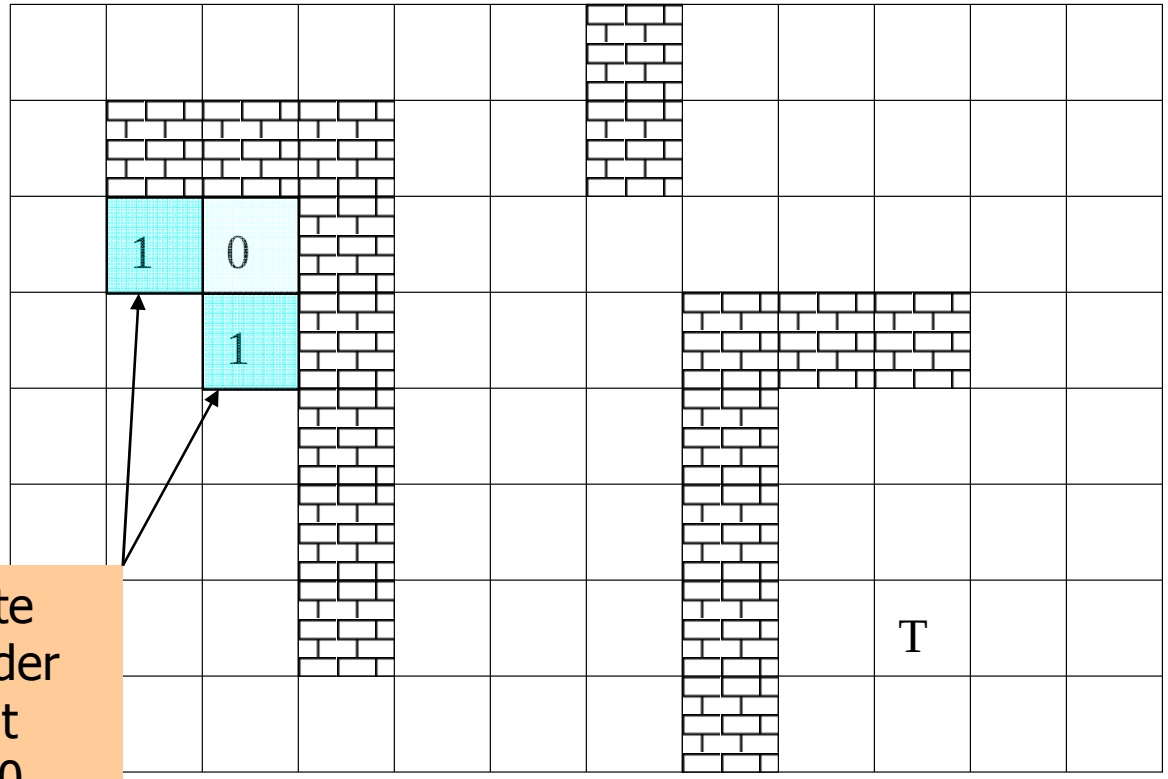
Schritt 0: Alle Zellen mit Weglänge 0:



Startposition eines Roboters

Markierung aller Zellen mit ihren Weglängen

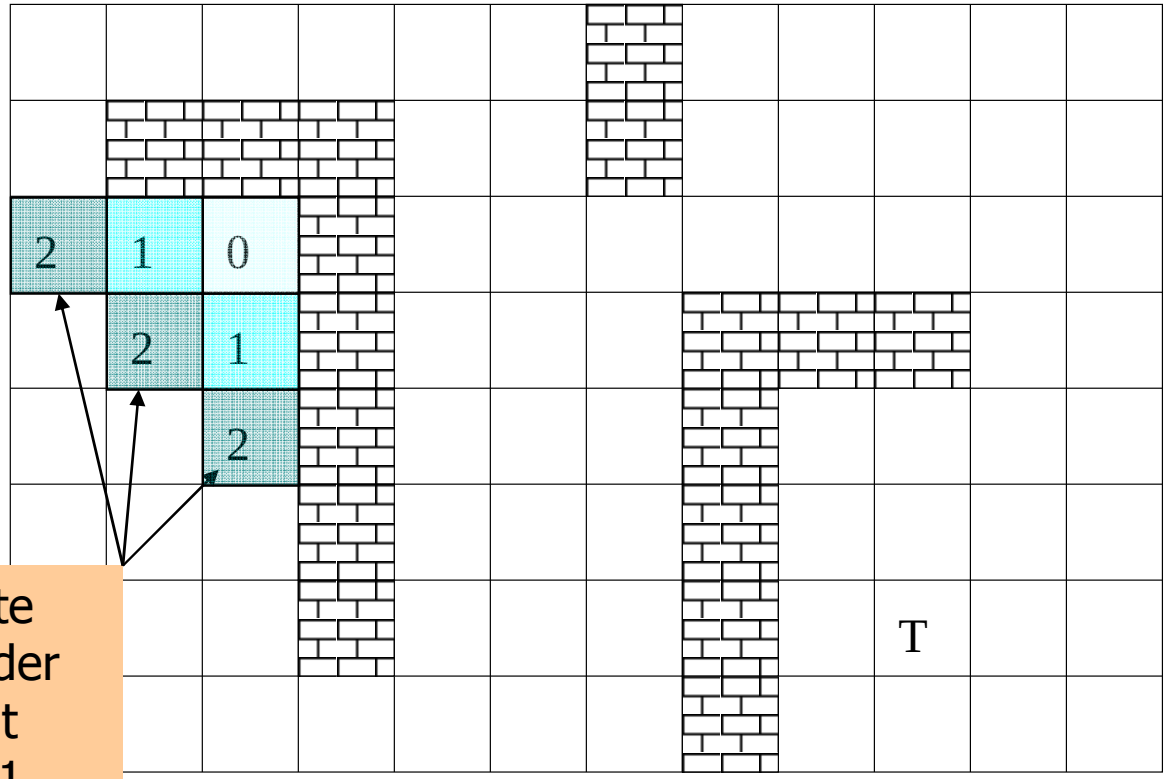
Schritt 1: Alle Zellen mit Weglänge 1:



Unmarkierte Nachbarn der Zelle(n) mit Weglänge 0

Markierung aller Zellen mit ihren Weglängen

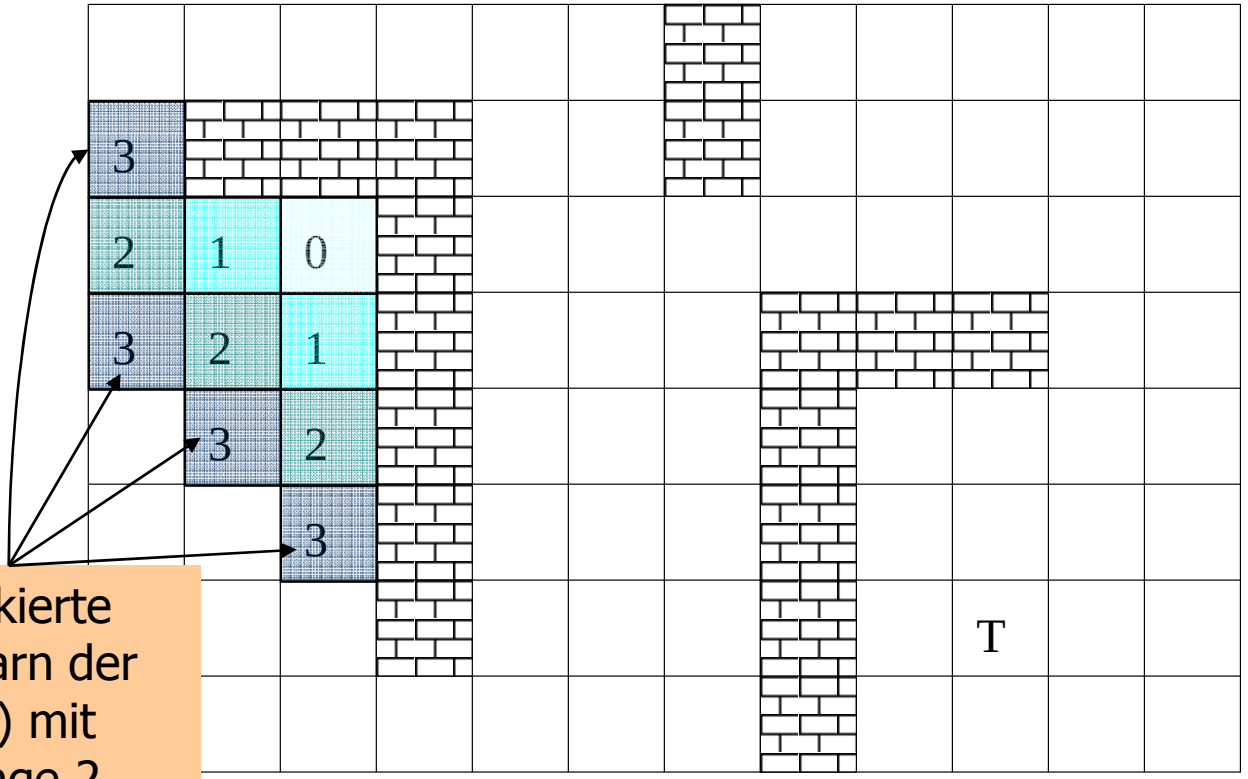
Schritt 2: Alle Zellen mit Weglänge 2:



Unmarkierte Nachbarn der Zelle(n) mit Weglänge 1

Markierung aller Zellen mit ihren Weglängen

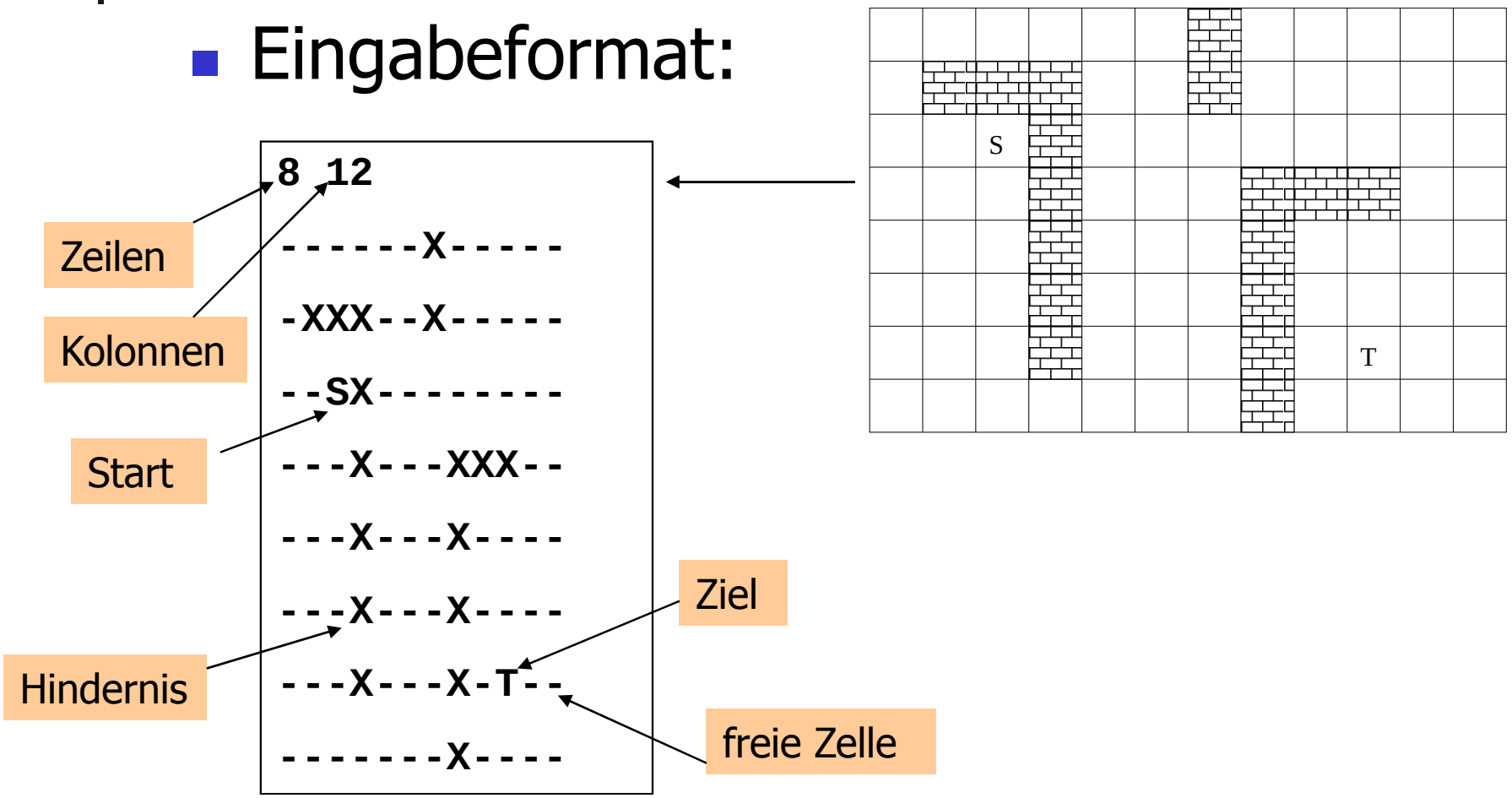
Schritt 3: Alle Zellen mit Weglänge 3:

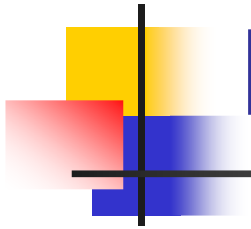


Unmarkierte Nachbarn der Zelle(n) mit Weglänge 2

Das Kürzeste-Wege-Programm

- Eingabeformat:





Das Kürzeste-Wege-Programm

- Einlesen der Dimensionen und Bereit-stellung eines zweidimensionalen Feldes für die Weglängen

```
int n; std::cin >> n; // number of rows
int m; std::cin >> m; // number of columns

// dynamically allocate twodimensional array of dimensions
// (n+2) x (m+2) to hold the floor plus extra walls around
int** const floor = new int*[n+2];
for (int r=0; r<n+2; ++r)
  floor[r] = new int[m+2];
```

Das Kürzeste-Wege-Programm

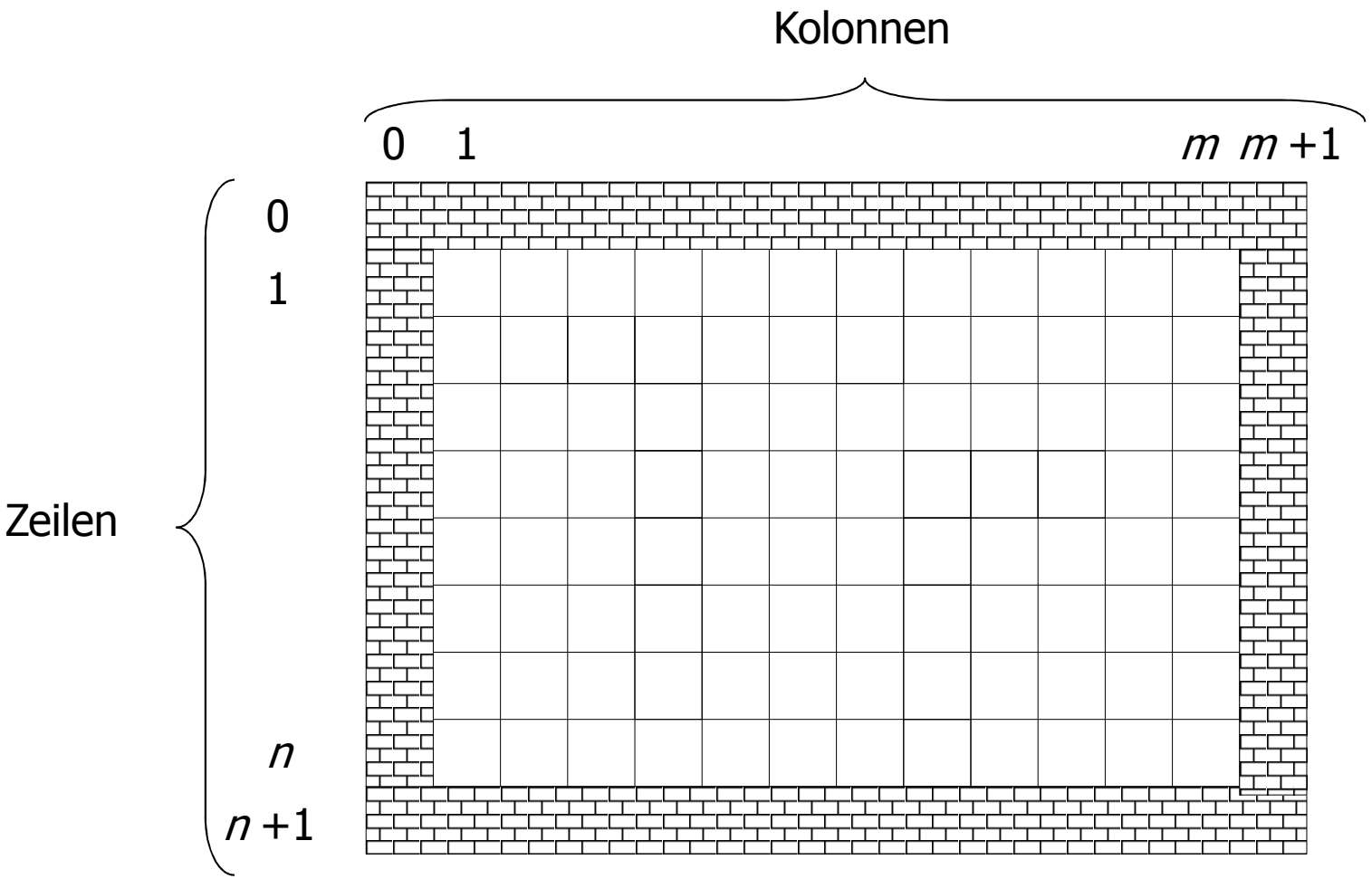
- Einlesen der Dimensionen und Bereitstellung eines zweidimensionalen Feldes für die Weglängen

```
int n; std::cin >> n; // number of rows
int m; std::cin >> m; // number of columns

// dynamically allocate twodimensional array of dimensions
// (n+2) x (m+2) to hold the floor plus extra walls around
int** const floor = new int*[n+2];
for (int r=0; r<n+2; ++r)
  floor[r] = new int[m+2];
```

Wächter (*sentinels*)

Das Kürzeste-Wege-Programm



Das Kürzeste-Wege-Programm

- Einlesen der Hallenbelegung und Initialisierung der Längen

```
int tr = 0;
int tc = 0;
for (int r=1; r<n+1; ++r)
  for (int c=1; c<m+1; ++c) {
    char entry = '-';
    std::cin >> entry;
    if      (entry == 'S') floor[r][c] = 0;
    else if (entry == 'T') floor[tr = r][tc = c] = -1;
    else if (entry == 'X') floor[r][c] = -2;
    else if (entry == '-') floor[r][c] = -1;
  }
```

Zielkoordinaten (Zeilen-/Kolonnenindex)

Das Kürzeste-Wege-Programm

- Einlesen der Hallenbelegung und Initialisierung der Längen

```
int tr = 0;
int tc = 0;
for (int r=1; r<n+1; ++r)
  for (int c=1; c<m+1; ++c) {
    char entry = '-';
    std::cin >> entry;
    if      (entry == 'S') floor[r][c] = 0;
    else if (entry == 'T') floor[tr = r][tc = c] = -1;
    else if (entry == 'X') floor[r][c] = -2;
    else if (entry == '-') floor[r][c] = -1;
  }
```

lies die Eingabe Zeile für Zeile (z.B. durch Umlenkung der Eingabe auf die Datei **`shortest_path0.dat`**)

Das Kürzeste-Wege-Programm

- Einlesen der Hallenbelegung und Initialisierung der Längen

```
int tr = 0;
int tc = 0;
for (int r=1; r<n+1; ++r)
  for (int c=1; c<m+1; ++c) {
    char entry = '-';
    std::cin >> entry;
    if      (entry == 'S') floor[r][c] = 0;
    else if (entry == 'T') floor[tr = r][tc = c] = -1;
    else if (entry == 'X') floor[r][c] = -2;
    else if (entry == '-') floor[r][c] = -1;
  }
```

Eingabezeichen in Zeile $r \in \{1,...,n\}$ und Kolonne $c \in \{1,...,m\}$

Das Kürzeste-Wege-Programm

- Einlesen der Hallenbelegung und Initialisierung der Längen

```
int tr = 0;
int tc = 0;
for (int r=1; r<n+1; ++r)
  for (int c=1; c<m+1; ++c) {
    char entry = '-';
    std::cin >> entry;
    if      (entry == 'S') floor[r][c] = 0;
    else if (entry == 'T') floor[tr = r][tc = c] = -1;
    else if (entry == 'X') floor[r][c] = -2;
    else if (entry == '-') floor[r][c] = -1;
  }
```

Länge bereits bekannt

Das Kürzeste-Wege-Programm

- Einlesen der Hallenbelegung und Initialisierung der Längen

```
int tr = 0;
int tc = 0;
for (int r=1; r<n+1; ++r)
  for (int c=1; c<m+1; ++c) {
    char entry = '-';
    std::cin >> entry;
    if      (entry == 'S') floor[r][c] = 0;
    else if (entry == 'T') floor[tr = r][tc = c] = -1;
    else if (entry == 'X') floor[r][c] = -2;
    else if (entry == '-') floor[r][c] = -1;
  }
```

Ziel: setze Koordinaten

-1: Länge noch unbekannt

Das Kürzeste-Wege-Programm

- Einlesen der Hallenbelegung und Initialisierung der Längen

```
int tr = 0;
int tc = 0;
for (int r=1; r<n+1; ++r)
  for (int c=1; c<m+1; ++c) {
    char entry = '-';
    std::cin >> entry;
    if      (entry == 'S') floor[r][c] = 0;
    else if (entry == 'T') floor[tr = r][tc = c] = -1;
    else if (entry == 'X') floor[r][c] = -2;
    else if (entry == '-') floor[r][c] = -1;
  }
```

-2: Länge nicht relevant (Hindernis)

Das Kürzeste-Wege-Programm

- Einlesen der Hallenbelegung und Initialisierung der Längen

```
int tr = 0;
int tc = 0;
for (int r=1; r<n+1; ++r)
  for (int c=1; c<m+1; ++c) {
    char entry = '-';
    std::cin >> entry;
    if      (entry == 'S') floor[r][c] = 0;
    else if (entry == 'T') floor[tr = r][tc = c] = -1;
    else if (entry == 'X') floor[r][c] = -2;
    else if (entry == '-') floor[r][c] = -1;
  }
```

-1: Länge noch unbekannt (freie Zelle)

Das Kürzeste-Wege-Programm

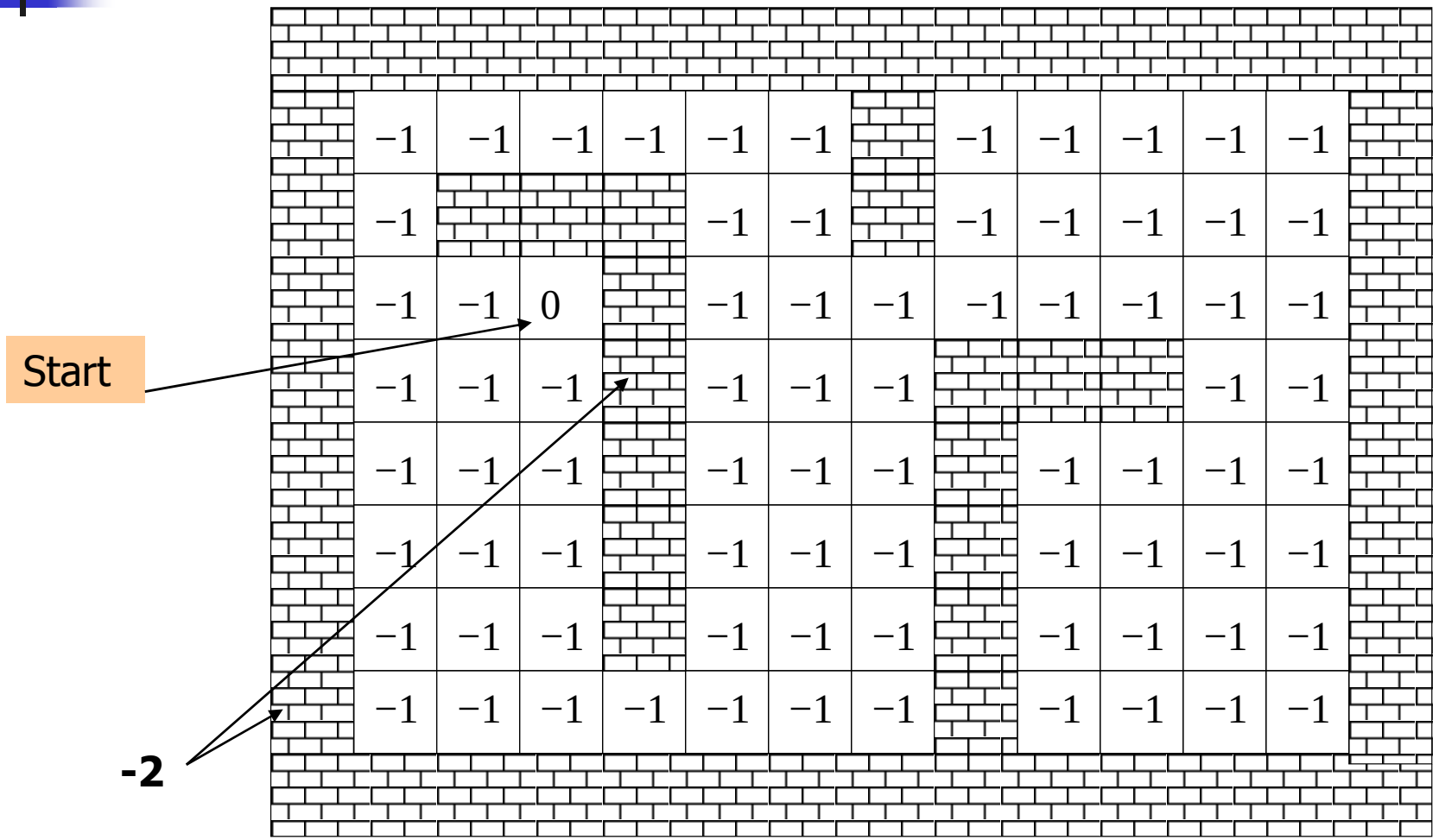
- Hinzufügen der umschliessenden "Wände"

```
for (int r=0; r<n+2; ++r)
  floor[r][0] = floor[r][m+1] = -2;
for (int c=0; c<m+2; ++c)
  floor[0][c] = floor[n+1][c] = -2;
```

Kolonnen 0 und $m+1$

Zeilen 0 und $n+1$

Das Kürzeste-Wege-Programm



Das Kürzeste-Wege-Programm

Hauptschleife: finde und markiere alle Zellen mit Weglängen i=1,2,3...

```
for (int i=1;; ++i) {
  bool progress = false;
  for (int r=1; r<n+1; ++r)
     for (int c=1; c<m+1; ++c) {
      if (floor[r][c] != -1) continue;
      if (floor[r-1][c] == i-1 || floor[r+1][c] == i-1 ||
          floor[r][c-1] == i-1 || floor[r][c+1] == i-1 ) {
        floor[r][c] = i; // label cell with i
        progress = true;
      }
    }
  if (!progress) break;
}
```

Das Kürzeste-Wege-Programm

```
for (int i=1;; ++i) {
  bool progress = false;
  for (int r=1; r<n+1; ++r)
     for (int c=1; c<m+1; ++c) {
      if (floor[r][c] != -1) continue;
      if (floor[r-1][c] == i-1 || floor[r+1][c] == i-1 ||
          floor[r][c-1] == i-1 || floor[r][c+1] == i-1 ) {
        floor[r][c] = i; // label cell with i
        progress = true;
      }
    }
  if (!progress) break;
}
```

Haben wir für dieses i eine Zelle gefunden?

Das Kürzeste-Wege-Programm

```
for (int i=1;; ++i) {
  bool progress = false;
  for (int r=1; r<n+1; ++r)
     for (int c=1; c<m+1; ++c) {
      if (floor[r][c] != -1) continue;
      if (floor[r-1][c] == i-1 || floor[r+1][c] == i-1 ||
          floor[r][c-1] == i-1 || floor[r][c+1] == i-1 ) {
        floor[r][c] = i; // label cell with i
        progress = true;
      }
    }
  if (!progress) break;
}
```

Iteriere über alle "echten" Zellen

Das Kürzeste-Wege-Programm

```
for (int i=1;; ++i) {
  bool progress = false;
  for (int r=1; r<n+1; ++r)
     for (int c=1; c<m+1; ++c) {
      if (floor[r][c] != -1) continue;
      if (floor[r-1][c] == i-1 || floor[r+1][c] == i-1 ||
          floor[r][c-1] == i-1 || floor[r][c+1] == i-1 ) {
        floor[r][c] = i; // label cell with i
        progress = true;
      }
    }
  if (!progress) break;
}
```

Betrachte Zelle in Zeile r $\in \{1,\ldots,n\}$ und Kolonne c $\in \{1,\ldots,m\}$:

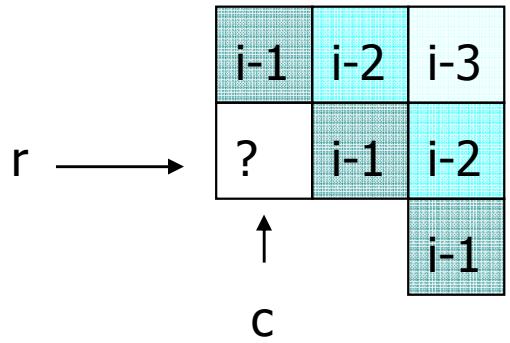
Fall 1: Hindernis, oder schon markiert

Das Kürzeste-Wege-Programm

```
for (int i=1;; ++i) {
  bool progress = false;
  for (int r=1; r<n+1; ++r)
     for (int c=1; c<m+1; ++c) {
      if (floor[r][c] != -1) continue;
      if (floor[r-1][c] == i-1 || floor[r+1][c] == i-1 ||
          floor[r][c-1] == i-1 || floor[r][c+1] == i-1 ) {
        floor[r][c] = i; // label cell with i
        progress = true;
      }
    }
  if (!progress) break;
}
```

Betrachte Zelle in Zeile r ∈ {1,...,n} und Kolonne c ∈ {1,...,m}:

Fall 2: Ein Nachbar hat bereits Weglänge i-1

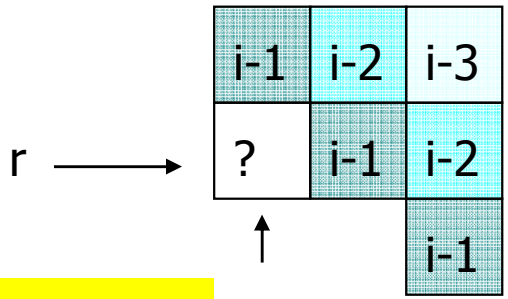


Das Kürzeste-Wege-Programm

```
for (int i=1;; ++i) {
  bool progress = false;
  for (int r=1; r<n+1; ++r)
     for (int c=1; c<m+1; ++c) {
      if (floor[r][c] != -1) continue;
      if (floor[r-1][c] == i-1 || floor[r+1][c] == i-1 ||
          floor[r][c-1] == i-1 || floor[r][c+1] == i-1 ) {
        floor[r][c] = i; // label cell with i
        progress = true;
      }
    }
  if (!progress) break;
}
```

Betrachte Zelle in Zeile r $\in \{1,\ldots,n\}$ und Kolonne c $\in \{1,\ldots,m\}$:

Fall 2: Ein Nachbar hat bereits Weglänge i-1



Durch die Wächter hat jede "echte" Zelle 4 Nachbarn!

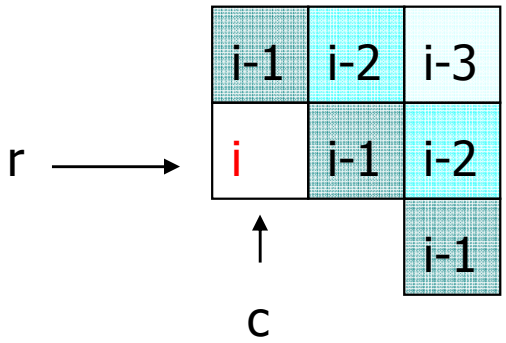
Das Kürzeste-Wege-Programm

```
for (int i=1;; ++i) {
  bool progress = false;
  for (int r=1; r<n+1; ++r)
     for (int c=1; c<m+1; ++c) {
      if (floor[r][c] != -1) continue;
      if (floor[r-1][c] == i-1 || floor[r+1][c] == i-1 ||
          floor[r][c-1] == i-1 || floor[r][c+1] == i-1 ) {
        floor[r][c] = i; // label cell with i
        progress = true;
      }
    }
  if (!progress) break;
}
```

Betrachte Zelle in Zeile r $\in \{1,\ldots,n\}$ und Kolonne c $\in \{1,\ldots,m\}$:

Fall 2: Ein Nachbar hat bereits Weglänge i-1

Markiere Zelle mit i



Das Kürzeste-Wege-Programm

```
for (int i=1;; ++i) {
  bool progress = false;
  for (int r=1; r<n+1; ++r)
     for (int c=1; c<m+1; ++c) {
      if (floor[r][c] != -1) continue;
      if (floor[r-1][c] == i-1 || floor[r+1][c] == i-1 ||
          floor[r][c-1] == i-1 || floor[r][c+1] == i-1 ) {
        floor[r][c] = i; // label cell with i
        progress = true;
      }
    }
  if (!progress) break;
}
```

Falls keine Zelle mehr markiert werden konnte, sind wir fertig (sonst geht's weiter mit i+1)

Das Kürzeste-Wege-Programm

- Markieren des kürzesten Weges durch "Rückwärtslaufen" vom Ziel zum Start

```
int r = tr; int c = tc;
while (floor[r][c] > 0) {
  const int d = floor[r][c] - 1;
  floor[r][c] = -3;
  if      (floor[r-1][c] == d) --r;
  else if (floor[r+1][c] == d) ++r;
  else if (floor[r][c-1] == d) --c;
  else                         ++c; // (floor[r][c+1] == d)
}
```

Zielzelle

Das Kürzeste-Wege-Programm

- Markieren des kürzesten Weges durch "Rückwärtslaufen" vom Ziel zum Start

```
int r = tr; int c = tc;
while (floor[r][c] > 0) {
  const int d = floor[r][c] - 1;
  floor[r][c] = -3;
  if      (floor[r-1][c] == d) --r;
  else if (floor[r+1][c] == d) ++r;
  else if (floor[r][c-1] == d) --c;
  else                         ++c; // (floor[r][c+1] == d)
}
```

Solange Startzelle noch nicht erreicht...

Das Kürzeste-Wege-Programm

- Markieren des kürzesten Weges durch "Rückwärtslaufen" vom Ziel zum Start

```
int r = tr; int c = tc;
while (floor[r][c] > 0) {
  const int d = floor[r][c] - 1;
  floor[r][c] = -3;
  if      (floor[r-1][c] == d) --r;
  else if (floor[r+1][c] == d) ++r;
  else if (floor[r][c-1] == d) --c;
  else                         ++c; // (floor[r][c+1] == d)
}
```

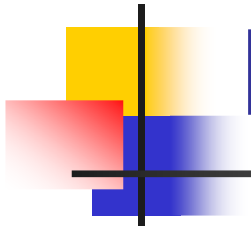
d = um eins kleinere Weglänge

Das Kürzeste-Wege-Programm

- Markieren des kürzesten Weges durch "Rückwärtslaufen" vom Ziel zum Start

```
int r = tr; int c = tc;
while (floor[r][c] > 0) {
  const int d = floor[r][c] - 1;
  floor[r][c] = -3;
  if      (floor[r-1][c] == d) --r;
  else if (floor[r+1][c] == d) ++r;
  else if (floor[r][c-1] == d) --c;
  else                         ++c; // (floor[r][c+1] == d)
}
```

Markiere Zelle (mit -3 zur Unterscheidung): sie liegt auf dem kürzesten Weg



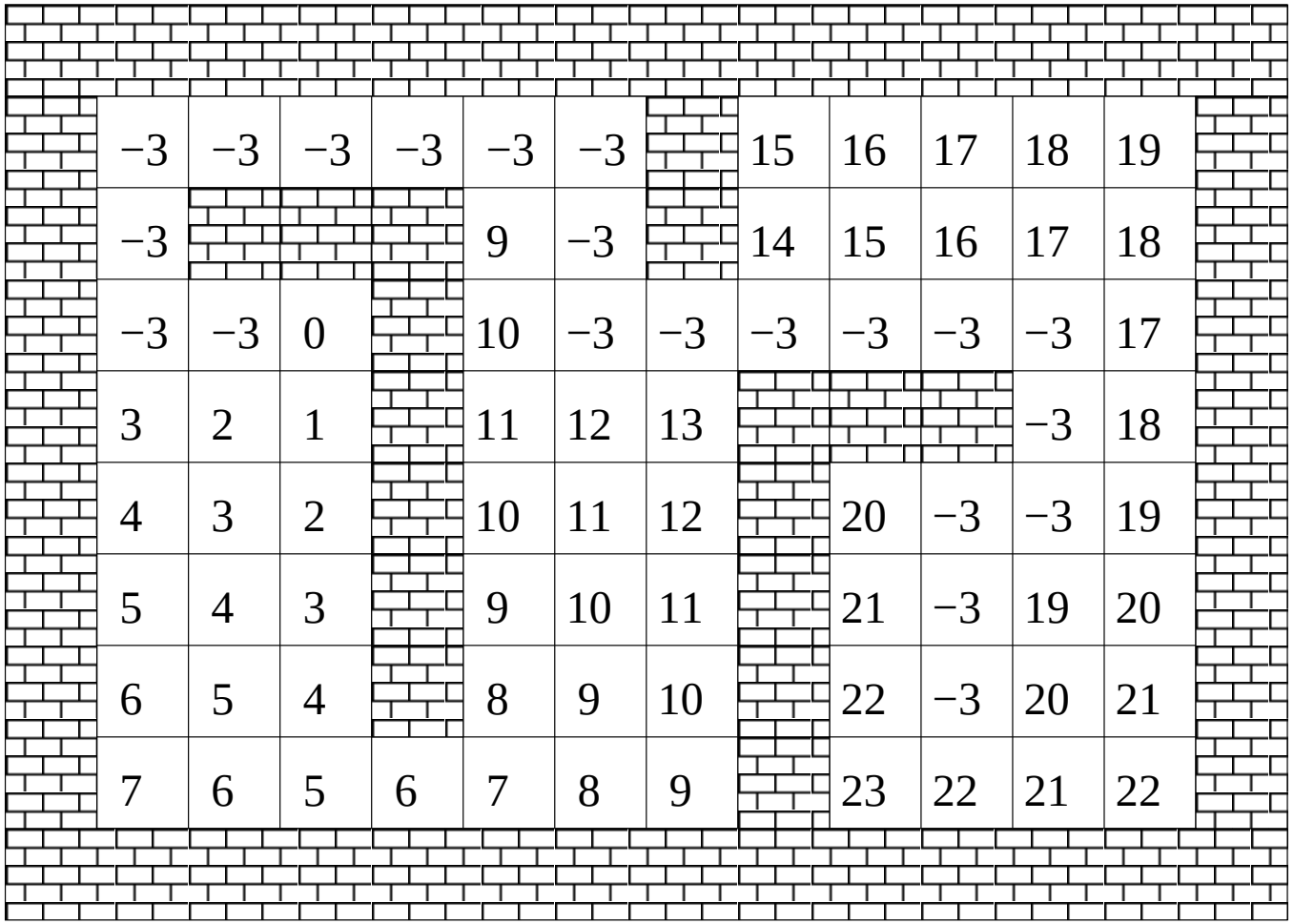
Das Kürzeste-Wege-Programm

- Markieren des kürzesten Weges durch "Rückwärtslaufen" vom Ziel zum Start

```
int r = tr; int c = tc;
while (floor[r][c] > 0) {
  const int d = floor[r][c] - 1;
  floor[r][c] = -3;
  if      (floor[r-1][c] == d) --r;
  else if (floor[r+1][c] == d) ++r;
  else if (floor[r][c-1] == d) --c;
  else                         ++c; // (floor[r][c+1] == d)
}
```

Gehe zu einer Nachbarzelle mit Weglänge **d** und wiederhole...

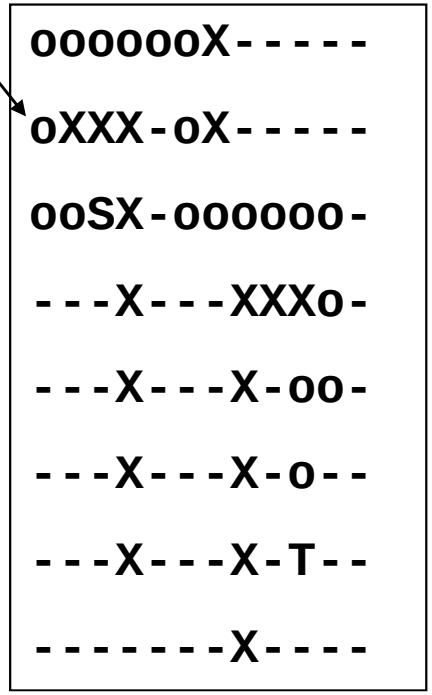
Das Kürzeste-Wege-Programm



Das Kürzeste-Wege-Programm

- Ausgabe:

auf dem kürzestem Weg



Das Kürzeste-Wege-Programm

- Ausgabe:

auf dem kürzestem Weg

```
for (int r=1; r<n+1; ++r) {
  for (int c=1; c<m+1; ++c)
    if      (floor[r][c] == 0)   std::cout << 'S';
    else if (r == tr && c == tc) std::cout << 'T';
    else if (floor[r][c] == -3)  std::cout << 'o';
    else if (floor[r][c] == -2)  std::cout << 'X';
    else                         std::cout << '-';
  std::cout << "\n";
}
```

```
oooooX-----
oXXX-oX-----
ooSX-oooooo-
---X---XXXo-
---X---X-oo-
---X---X-o--
---X---X-T--
-------X----
```

Das Kürzeste-Wege-Programm

- Ausgabe:

auf dem kürzestem Weg

```
for (int r=1; r<n+1; ++r) {
  for (int c=1; c<m+1; ++c)
    if      (floor[r][c] == 0)   std::cout << 'S';
    else if (r == tr && c == tc) std::cout << 'T';
    else if (floor[r][c] == -3)  std::cout << 'o';
    else if (floor[r][c] == -2)  std::cout << 'X';
    else                         std::cout << '-';
  std::cout << "\n";
}
```

```
ooooooX-----
oXXX-oX-----
ooSX-oooooo-
---X---XXXo-
---X---X-oo-
---X---X-o--
---X---X-T--
-------X----
```

Das Kürzeste-Wege-Programm

- Ausgabe:

auf dem kürzestem Weg

```
for (int r=1; r<n+1; ++r) {
  for (int c=1; c<m+1; ++c)
    if      (floor[r][c] == 0)   std::cout << 'S';
    else if (r == tr && c == tc) std::cout << 'T';
    else if (floor[r][c] == -3)  std::cout << 'o';
    else if (floor[r][c] == -2)  std::cout << 'X';
    else                         std::cout << '-';
  std::cout << "\n";
}
```

```
ooooooX-----
oXXX-oX-----
ooSX-oooooo-
---X---XXXo-
---X---X-oo-
---X---X-o--
---X---X-T--
-------X----
```

Das Kürzeste-Wege-Programm

- Ausgabe:

auf dem kürzestem Weg

```
for (int r=1; r<n+1; ++r) {
  for (int c=1; c<m+1; ++c)
    if      (floor[r][c] == 0)   std::cout << 'S';
    else if (r == tr && c == tc) std::cout << 'T';
    else if (floor[r][c] == -3)  std::cout << 'o';
    else if (floor[r][c] == -2)  std::cout << 'X';
    else                         std::cout << '-';
  std::cout << "\n";
}
```

```
ooooooX-----
oXXX-oX-----
ooSX-oooooo-
---X---XXXo-
---X---X-oo-
---X---X-o--
---X---X-T--
-------X----
```

Das Kürzeste-Wege-Programm

- Ausgabe:

auf dem kürzestem Weg

```
for (int r=1; r<n+1; ++r) {
  for (int c=1; c<m+1; ++c)
    if      (floor[r][c] == 0)   std::cout << 'S';
    else if (r == tr && c == tc) std::cout << 'T';
    else if (floor[r][c] == -3)  std::cout << 'o';
    else if (floor[r][c] == -2)  std::cout << 'X';
    else                         std::cout << '-';
  std::cout << "\n";
}
```

```
ooooooX-----
oXXX-oX-----
ooSX-oooooo-
---X---XXXo-
---X---X-oo-
---X---X-o--
---X---X-T--
-------X----
```

Das Kürzeste-Wege-Programm

- Ausgabe:

auf dem kürzestem Weg

```
for (int r=1; r<n+1; ++r) {
  for (int c=1; c<m+1; ++c)
    if      (floor[r][c] == 0)   std::cout << 'S';
    else if (r == tr && c == tc) std::cout << 'T';
    else if (floor[r][c] == -3)  std::cout << 'o';
    else if (floor[r][c] == -2)  std::cout << 'X';
    else                         std::cout << '-';
  std::cout << "\n";
}
```

```
ooooooX-----
oXXX-oX-----
ooSX-oooooo-
---X---XXXo-
---X---X-oo-
---X---X-o--
---X---X-T--
-------X----
```

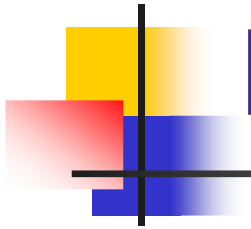
Das Kürzeste-Wege-Programm

- *Last, but not least* : lösche die auf dem Heap bereitgestellten Felder

```
for (int r=0; r<n+2; ++r)
  delete[] floor[r];
delete[] floor;
```

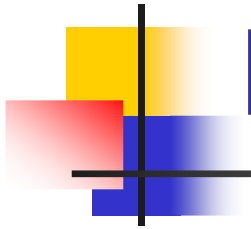
Feld für die Zeile mit Index *r*

Feld von Zeigern auf die *n* +2 Zeilen



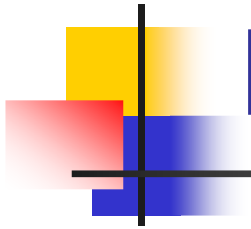
Das Kürzeste-Wege-Programm

- Das Programm kann recht langsam sein, weil für jedes i *alle* Zellen durchlaufen werden



Das Kürzeste-Wege-Programm

- Das Programm kann recht langsam sein, weil für jedes i *alle* Zellen durchlaufen werden
- Verbesserung: durchlaufe jeweils nur die Nachbarn der Zellen mit Markierung i-1



Das Kürzeste-Wege-Programm

- Das Programm kann recht langsam sein, weil für jedes i *alle* Zellen durchlaufen werden
- Verbesserung: durchlaufe jeweils nur die Nachbarn der Zellen mit Markierung i-1
- *Challenge*