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

Zeichen und Texte

- Texte haben wir schon gesehen:

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

String-Literal

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

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

Der Typ `char` ("character")

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

```
char c = 'a'
```

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

Literal vom Typ `char`

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'` ?)
  - Werte belegen meistens 8 Bit

Wertebereich:

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

Der ASCII-Code

- definiert konkrete Konversionregeln `char` → `int / unsigned int`
- wird von fast allen Plattformen benutzt

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`

Zeichen → {0,...,127}

`'A','B',...,'Z'` → 65, 66,...,90

`'a','b',...,'z'` → 97, 98,...,122

Texte

- sind repräsentierbar als Felder mit zugrundeliegendem Typ **`char`**

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

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

Texte

- sind repräsentierbar als Felder mit zugrundeliegendem Typ **`char`**

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

- können auch durch String-Literale definiert werden

```
char text[] = "bool"
```

"kennt" seine Länge!

definiert ein Feld der Länge 5, das dem Text "bool" entspricht und *null-terminiert* ist (Extrazeichen `'\0'` wird am Ende angehängt)

Anwendung: *String matching*

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

"Trivialer" Algorithmus:

```
Gallia est omnis divisa in partes tres
  ≠
visa
```

Anwendung: *String matching*

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

"Trivialer" Algorithmus:

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Anwendung: *String matching*

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

"Trivialer" Algorithmus:

```
Gallia est omnis divisa in partes tres
                    = (gefunden!)
                visa
```

Anwendung: *String matching*

```
#include<iostream>

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

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

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

  unsigned int w = 0; // number of characters read so far
  unsigned int i = 0; // index where t logically starts
  ...
```

Muster "fest verdrahtet" in diesem Program (aber siehe *Details* im Skript)

Anwendung: *String matching*

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

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  unsigned int m = 0;
  for (char* p = s; *p != '\0'; ++p) ++m;

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

  unsigned int w = 0; // number of characters read so far
  unsigned int i = 0; // index where t logically starts
  ...
```

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

Anwendung: *String matching*

```
#include<iostream>

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

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

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  char* t = new char[m];

  unsigned int w = 0; // number of characters read so far
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  ...
```

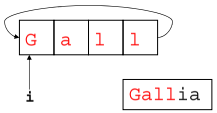

Anwendung: *String matching*

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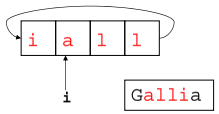
  ...
```



Anwendung: *String matching*

```
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{
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  char s[] = "bool";

  // determine search string length m
  unsigned int m = 0;
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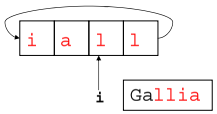
```



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;
}
```

Leerzeichen und Zeilenumbrüche sollen *nicht* ignoriert werden

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;)
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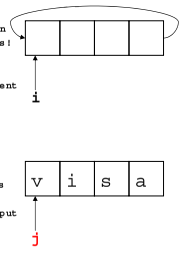
      i = (i+1)%m;  // of string and window
    } else break;   // no more characters in the input
  else ++j; // match: go to next character

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



w == 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
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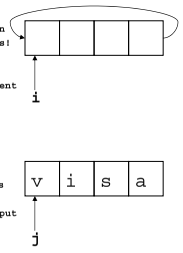
      i = (i+1)%m;  // of string and window
    } else break;   // no more characters in the input
  else ++j; // match: go to next character

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



w == 0

Anwendung: *String matching*

```
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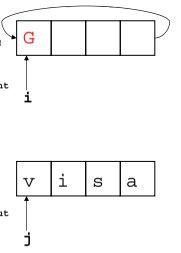
  // compare search string with window at j-th element
  if (w < m || s[j] != t[(i+j)%m])
    // input text still too short, or mismatch:
    // advance window by replacing first character
    if (std::cin >> t[i]) {
      std::cout << t[i];
      ++w;          // one more character read
      j = 0;        // 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 == 0

Anwendung: *String matching*

```
...
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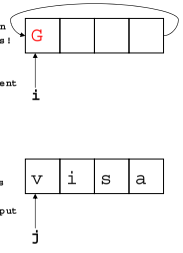
std::cin >> std::noskipws; // don't skip whitespaces!

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;
}
```

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



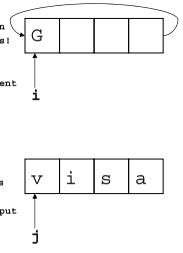
w == 0

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;
}
```



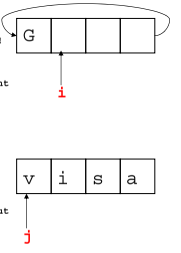
w == 1

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;
}
```



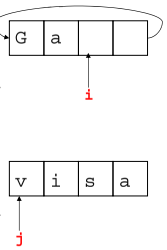
w == 1

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;
}
```



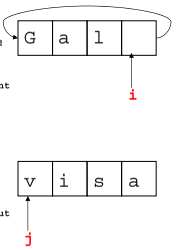
w == 2

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;
}
```



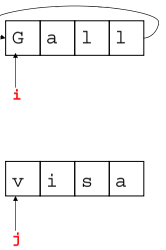
w == 3

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;
}
```



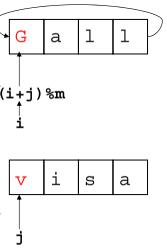
w == 4

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;
}
```



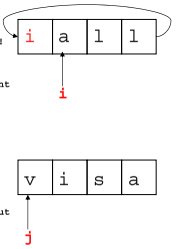
w == 4

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;
}
```



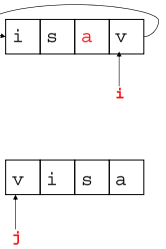
w == 5

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;
}
```



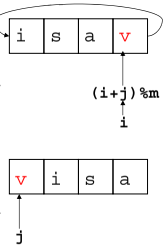
w == 23

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;
}
```



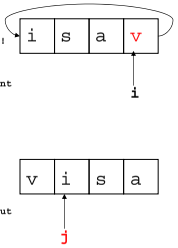
w == 23

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]) {
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      ++w;          // one more character read
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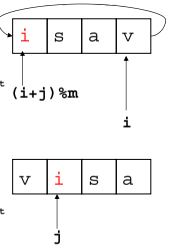
std::cout << "\n";
delete[] t;
return 0;
}
```



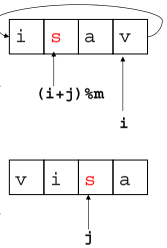
w == 23

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;
}
```



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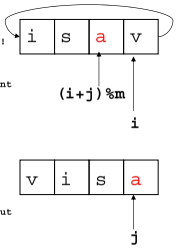

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delete[] t;
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```

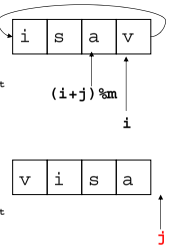

w == 23

Anwendung: *String matching*

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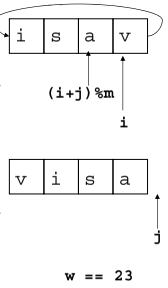
    } else break;   // no more characters in the input
  else ++j; // match: go to next character

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

false



Anwendung: *String matching*

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      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;
}
```
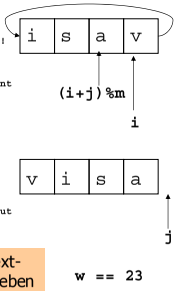

Fertig! Die ersten 23 Text-zeichen wurden ausgegeben



Anwendung: *String matching*

- Aufruf des Programms z.B. durch

```
./string_matching < eratosthenes.C
```

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.C
```

- Ausgabe:

```
// Program: eratosthenes.C
// Calculate prime numbers in {2,...,999} using
// Eratosthenes' sieve.

#include <iostream>

int main()
{
  // definition and initialization: provides us with
  // Booleans crossed_out[0],..., crossed_out[999]
  bool
```

Anwendung: *String matching*

- Aufruf des Programms z.B. durch

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

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

Anwendung: *String matching*

- Aufruf des Programms z.B. durch

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

- Der triviale Algorithmus ist meistens schnell, aber nicht immer (Übung)
- *Knuth-Morris-Pratt*-Algorithmus ist immer schnell

Mehrdimensionale Felder

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

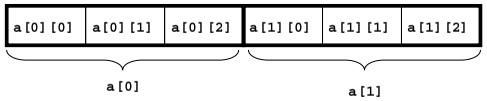
Mehrdimensionale Felder

- sind Felder von Feldern

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

`a` hat zwei Elemente, und jedes von ihnen ist ein Feld der Länge 3 mit zugrundeliegendem Typ `int`

Im Speicher: *flach*



Mehrdimensionale Felder

- sind Felder von Feldern

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

Im Kopf: Matrix, Tabelle,...

Kolonnen

Zeilen

	0	1	2
0	a[0][0]	a[0][1]	a[0][2]
1	a[1][0]	a[1][1]	a[1][2]

Mehrdimensionale Felder

- sind Felder von Feldern von Feldern...

```
T a[expr1]...[exprk]
```

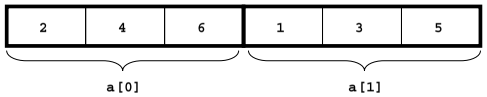
konstante Ausdrücke!

`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

Initialisierung:

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

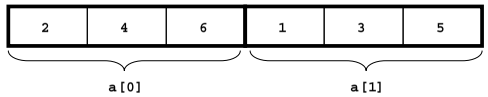


Mehrdimensionale Felder

Initialisierung:

erste Dimension kann weggelassen werden

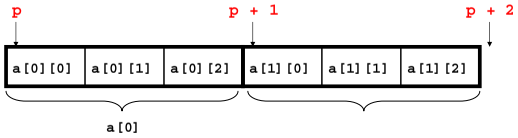
```
int a[][3] =
{
 {2,4,6}, {1,3,5}
}
```



Zeiger auf Felder

Wie iteriert man natürlich über ein mehrdimensionales Feld?

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



Zeiger auf Felder

Wie iteriert man natürlich über ein mehrdimensionales Feld?

```
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 mehrdimensionales Feld?

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

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- -dimensionales Feld?

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

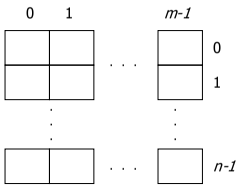
Ohne Kla eld von 3 Zeigern auf `int`

```
 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?



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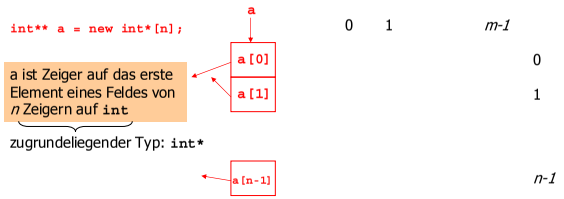

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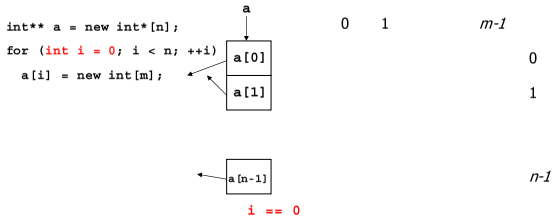
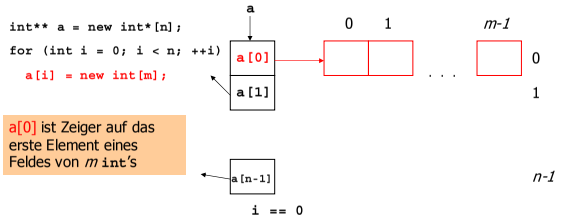


Felder von Zeigern

- Wie bekommen wir mehrdimensionale Felder mit variablen Dimensionen?

a[0] ist Zeiger auf das erste Element eines Feldes von *m* int's



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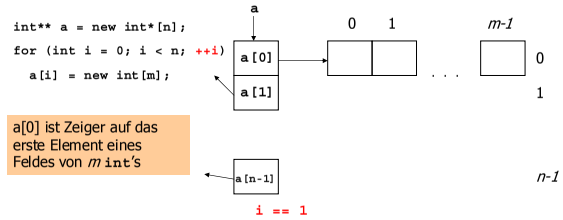
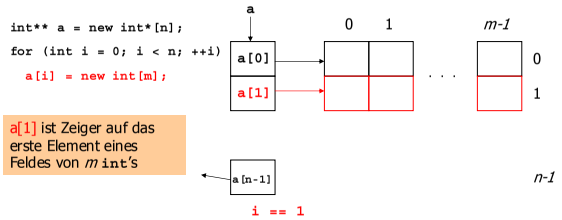


Felder von Zeigern

- Wie bekommen wir mehrdimensionale Felder mit variablen Dimensionen?

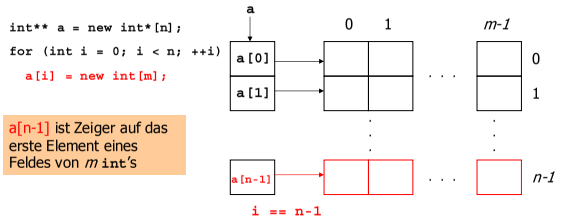
a[1] ist Zeiger auf das erste Element eines Feldes von *m* int's



Felder von Zeigern

- Wie bekommen wir mehrdimensionale Felder mit variablen Dimensionen?

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



Felder von Zeigern

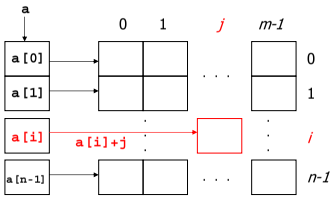
- Wie bekommen wir mehrdimensionale Felder mit variablen Dimensionen?

Wahlfreier Zugriff:

`a[i][j]`

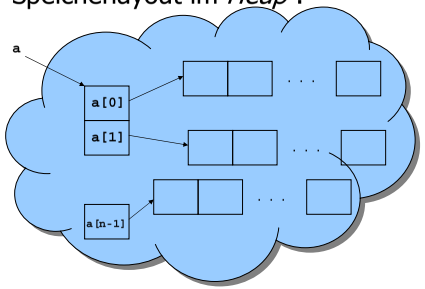
`*(a[i]+j)`

Zeiger



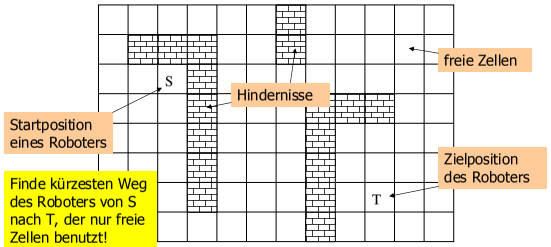
Felder von Zeigern

- Speicherlayout im *Heap* :



Anwendung: kürzeste Wege

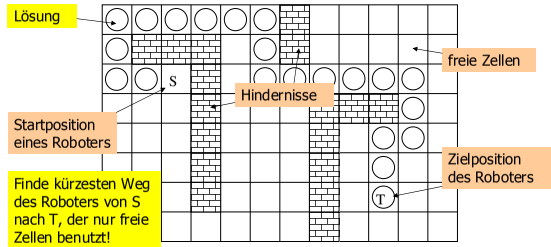
Fabrik-Halle ($n \times m$ quadratische Zellen)



Finde kürzesten Weg des Roboters von S nach T, der nur freie Zellen benutzt!

Anwendung: kürzeste Wege

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



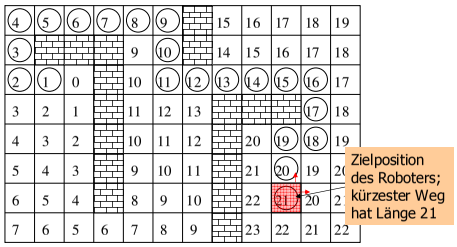
Finde kürzesten Weg des Roboters von S nach T, der nur freie Zellen benutzt!

Ein (scheinbar) anderes Problem

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

Das löst auch das Original-Problem:

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



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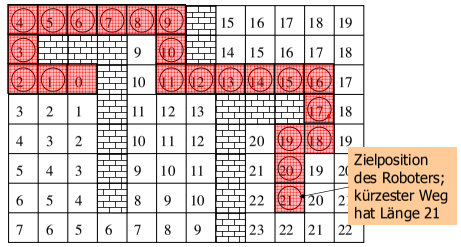
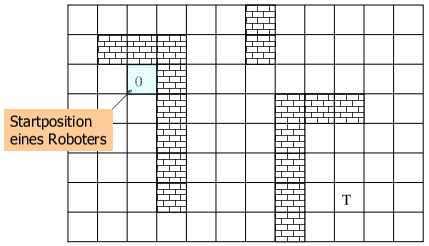
Weglänge 21 (optimal)



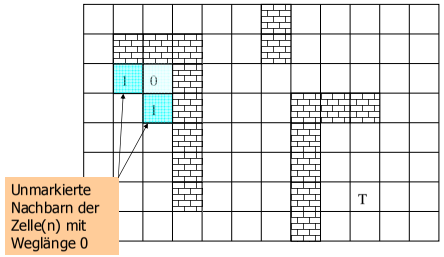
Markierung aller Zellen mit ihren Weglängen

Schritt 0: Alle Zellen mit Weglänge 0:



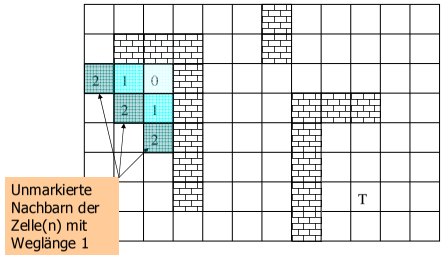
Markierung aller Zellen mit ihren Weglängen

Schritt 1: Alle Zellen mit Weglänge 1:



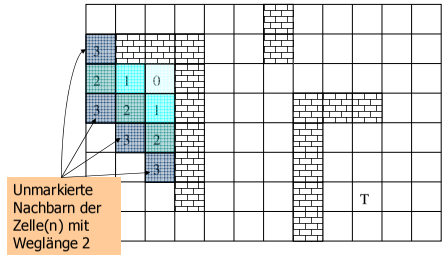
Markierung aller Zellen mit ihren Weglängen

Schritt 2: Alle Zellen mit Weglänge 2:



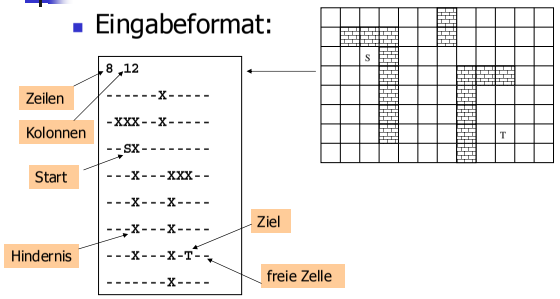
Markierung aller Zellen mit ihren Weglängen

Schritt 3: Alle Zellen mit Weglänge 3:



Das Kürzeste-Wege-Programm

- Eingabeformat:



Das Kürzeste-Wege-Programm

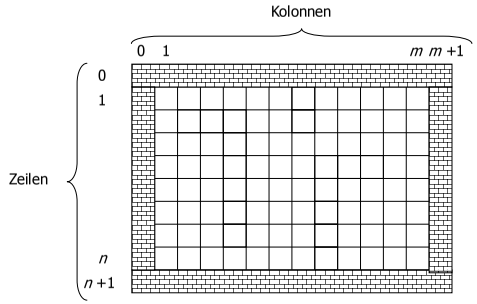
- Einlesen der Dimensionen und Bereitstellung eines zweidimensionalen Feldes für die Weglängen

```
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** 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) {
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    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)
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    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

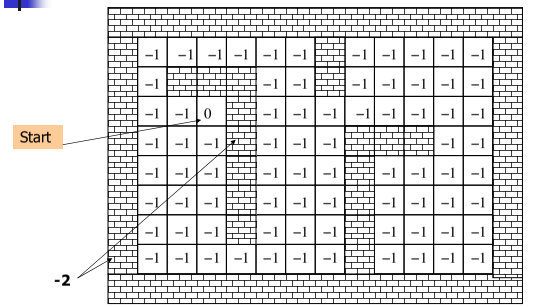
- Hinzufügen der umschliessenden "Wände"

```
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

Haben wir für dieses i eine Zelle gefunden?

```
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

Iteriere über alle "echten" Zellen

```
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;
}
```

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

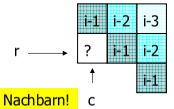
Fall 1: Hindernis, oder schon markiert

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



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

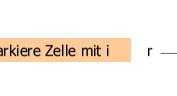
Das Kürzeste-Wege-Programm

```
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 ∈ {1,...,n} und Kolonne c ∈ {1,...,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) {
  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) {
  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) {
  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) {
  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) {
  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

–3	–3	–3	–3	–3	–3	15	16	17	18	19
–3				9	–3	14	15	16	17	18
–3	–3	0		10	–3	–3	–3	–3	–3	17
3	2	1		11	12	13			–3	18
4	3	2		10	11	12	20	–3	–3	19
5	4	3		9	10	11	21	–3	19	20
6	5	4		8	9	10	22	–3	20	21
7	6	5	6	7	8	9	23	22	21	22

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-ooooooo
---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
- Verbesserung: durchlaufe jeweils nur die Nachbarn der Zellen mit Markierung i-1
- *Challenge* : der leichteste bisher...