185.190 Effiziente Programme

Aufgabe: Hash-Tabelle

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WS12/13

Ausgangssituation

- Testaufruf:
  - `gcc -lm hash.c -o hash`
  - `perf stat -e cycles,cache-misses,branch-misses,instructions ./hash input input2`
- Ergebnis:
  - Cycles: 6,156,600,783
  - Instructions: 1,939,017,297
  - Cache-misses: 37,721,251
  - Branch mispredictions: 18,758,092
- Testrechner:
  - Intel Core i5-2520M CPU @ 2.50GHz
  - Cache-size:
    - Lvl 3: 3072 KB
    - Lvl 2: 512 KB
    - Lvl 1: 128 KB
  - RAM: 4GB DDR-3

Schritt 1

```
gcc -O3 -lm hash.c -o hash
```

Vorher:

- Cycles: 6,156,600,783
- Instructions: 1,939,017,297
- Cache-misses: 37,721,251
- Branch mispredictions: 18,758,092

Nachher:

- Cycles: 3,705,108,800 ($+39,82\%$)
- Instructions: 1,158,823,277 ($+40,24\%$)
- Cache-misses: 37,394,499 ($+0,87\%$)
- Branch mispredictions: 20,203,186 ($-7,70\%$)

Code: Schritt 2

Inlining

```
inline unsigned long hash(char *addr, size_t len);
inline void insert(char *keyaddr, size_t keylen, int
    value);
inline int lookup(char *keyaddr, size_t keylen);
```

Schritt 2

Inlining

Vorher:

- Cycles: 3,705,108,800
- Instructions: 1,158,823,277
- Cache-misses: 37,394,499
- Branch mispredictions: 20,203,186

Nachher:

- Cycles: 3,995,922,639 ($-7,85\%$)
- Instructions: 1,158,154,470 ($+0,06\%$)
- Cache-misses: 37,389,502 ($+0,01\%$)
- Branch mispredictions: 20,691,809 ($-2,42\%$)

Keine Verbesserung $\Rightarrow$ entfernt.

Code: Schritt 3

Packed

```
struct hashnode {
        char *keyaddr;
        size_t keylen;
        int value;
} __attribute__((__packed__));
```

Schritt 3

Packed

Vorher:

- Cycles: 3,705,108,800
- Instructions: 1,158,823,277
- Cache-misses: 37,394,499
- Branch mispredictions: 20,203,186

Nachher:

- Cycles: 3,760,116,819 ($-1,48\%$)
- Instructions: 1,158,688,286 ($+0,01\%$)
- Cache-misses: 37,372,930 ($+0,06\%$)
- Branch mispredictions: 19,799,458 ($+2,0\%$)

Verschlechterung $\Rightarrow$ entfernt.

Code: Schritt 4

Lineares Sondieren

```
void insert(char *keyaddr, size_t keylen, int value) {
    struct hashnode **l;
    int startPosition = hash(keyaddr, keylen) & (HASHSIZE-1);
    int position = startPosition;
    do {
        l = &ht[position];
        position = (position + 1) % HASHSIZE;
    } while(*l != NULL && position != startPosition);

    if (*l == NULL) {
        struct hashnode *n = malloc(sizeof(struct hashnode));
        n->keyaddr = keyaddr;
        n->keylen = keylen;
        n->value = value;
        *l = n;
    }
}
```

Schritt 4

Lineares Sondieren

Vorher:

- Cycles: 3,705,108,800
- Instructions: 1,158,823,277
- Cache-misses: 37,394,499
- Branch mispredictions: 20,203,186

Nachher:

- Cycles: 4,588,844,030 ($-23,85\%$)
- Instructions: 1,315,414,647 ($-13,51\%$)
- Cache-misses: 58,530,839 ($-56,52\%$)
- Branch mispredictions: 25,859,851 ($-28,00\%$)

Verschlechterung $\Rightarrow$ entfernt.

Code: Schritt 5 (1/2)

Quadratisches Sondieren

```
void insert(char *keyaddr, size_t keylen, int value) {
    struct hashnode **l;
    int startPosition = hash(keyaddr, keylen) & (HASHSIZE-1);
    int position = startPosition; int i = 0;
    do {
        l = &ht[position];
        position = (startPosition + (int) pow(-1, i) + (i*i/2))
    % HASHSIZE;
        i++;
    } while(*l != NULL && position != startPosition);

    if (*l == NULL) {
        struct hashnode *n = malloc(sizeof(struct hashnode));
        n->keyaddr = keyaddr;
        n->keylen = keylen;
        n->value = value;
        *l = n;
    }
}
```

Code: Schritt 5 (2/2)

Quadratisches Sondieren

```
int lookup(char *keyaddr, size_t keylen) {
    int startPosition = hash(keyaddr, keylen) & (HASHSIZE-1);
    int position = startPosition;
    struct hashnode *l;
    int i = 0;
    do {
        l = ht[position];
        if (l == NULL) {
            break;
        }
        if (keylen == l->keylen && memcmp(keyaddr, l->keyaddr,
    keylen) == 0) {
            return l->value;
        }
        position = (startPosition + (int) pow(-1, i) + (i*i/2))
    % HASHSIZE;
        i++;
    } while(position != startPosition);
    return -1;
}
```

Schritt 5

Quadratisches Sondieren

Vorher:

- Cycles: 3,705,108,800
- Instructions: 1,158,823,277
- Cache-misses: 37,394,499
- Branch mispredictions: 20,203,186

Nachher:

- Cycles: 5,948,874,039 ($-60,56\%$)
- Instructions: 2,588,119,362 ($-123,34\%$)
- Cache-misses: 43,166,841 ($-15,44\%$)
- Branch mispredictions: 22,792,713 ($-12,82\%$)

Verschlechterung $\Rightarrow$ entfernt.

Code: Schritt 6 (1/2)

Memoization

```
struct cachenode {
        struct cachenode *next;
        int value;
};
```

Code: Schritt 6 (2/2)

Memoization

```
int main(int argc, char *argv[]) {
    ...
    struct cachenode *first_cn = NULL;
    struct cachenode *current_cn;
    ...
    if (i == 0) {
        currentLookup = lookup(p, nextp - p);
        if (first_cn == NULL) {
            first_cn = malloc(sizeof(struct cachenode));
            current_cn = first_cn;
        } else {
            current_cn->next = malloc(sizeof(struct cachenode));
            current_cn = current_cn->next;
        }
        current_cn->next = NULL;
        current_cn->value = currentLookup;
    } else {
        currentLookup = current_cn->value;
        current_cn = current_cn->next;
    } ...
}
```

Schritt 6

Memoization

Vorher:

- Cycles: 3,705,108,800
- Instructions: 1,158,823,277
- Cache-misses: 37,394,499
- Branch mispredictions: 20,203,186

Nachher:

- Cycles: 1,223,009,952 ($+66,99\%$)
- Instructions: 867,096,107 ($+25,17\%$)
- Cache-misses: 5,077,492 ($+86,42\%$)
- Branch mispredictions: 7,507,892 ($+62,84\%$)

Verbesserung $\Rightarrow$ beibehalten.

Code: Schritt 7

Memoization 2: dynamisches Array

```
int main(int argc, char *argv[]) {
    ...
    int currentLookup;
    int *cache = calloc(HASHSIZE, sizeof(int));
    int cacheSize = HASHSIZE;
    int cacheCounter;
    ...
    if (i == 0) {
        currentLookup = lookup(p, nextp - p);
        if (cacheCounter >= cacheSize) {
            realloc(cache, sizeof(int));
            cacheSize++;
        }
        cache[cacheCounter] = currentLookup;
    } else {
        currentLookup = cache[cacheCounter];
    }
    r = ((unsigned long)r) * 2654435761L + currentLookup;
    ...
}
```

Schritt 7

Memoization 2 (dynamisches Array)

Vorher:

- Cycles: 1,223,009,952
- Instructions: 867,096,107
- Cache-misses: 5,077,492
- Branch mispredictions: 7,507,892

Nachher:

- Cycles: 917,739,423 ($+24,96\%$)
- Instructions: 702,170,463 ($+19,02\%$)
- Cache-misses: 4,647,945 ($+8,46\%$)
- Branch mispredictions: 7,421,590 ($+1,15\%$)

Verbesserung $\Rightarrow$ beibehalten.

Code: Schritt 8

Memoization 3 (Optimierung der Reallokierung)

```
#define CACHE_ALLOC_STEP_SIZE 96
int main(int argc, char *argv[]) {
    ...
    int currentLookup;
    int *cache = calloc(HASHSIZE, sizeof(int));
    int cacheSize = HASHSIZE; int cacheCounter;
    ...
    if (i == 0) {
        currentLookup = lookup(p, nextp - p);
        if (cacheCounter >= cacheSize) {
            cache = realloc(cache, CACHE_ALLOC_STEP_SIZE *
    sizeof(int));
            cacheSize += CACHE_ALLOC_STEP_SIZE;
        }
        cache[cacheCounter] = currentLookup;
    } else {
        currentLookup = cache[cacheCounter];
    }
    r = ((unsigned long)r) * 2654435761L + currentLookup;
    ...
}
```

Schritt 8

Memoization 3 (Optimierung der Reallokierung)

Vorher:

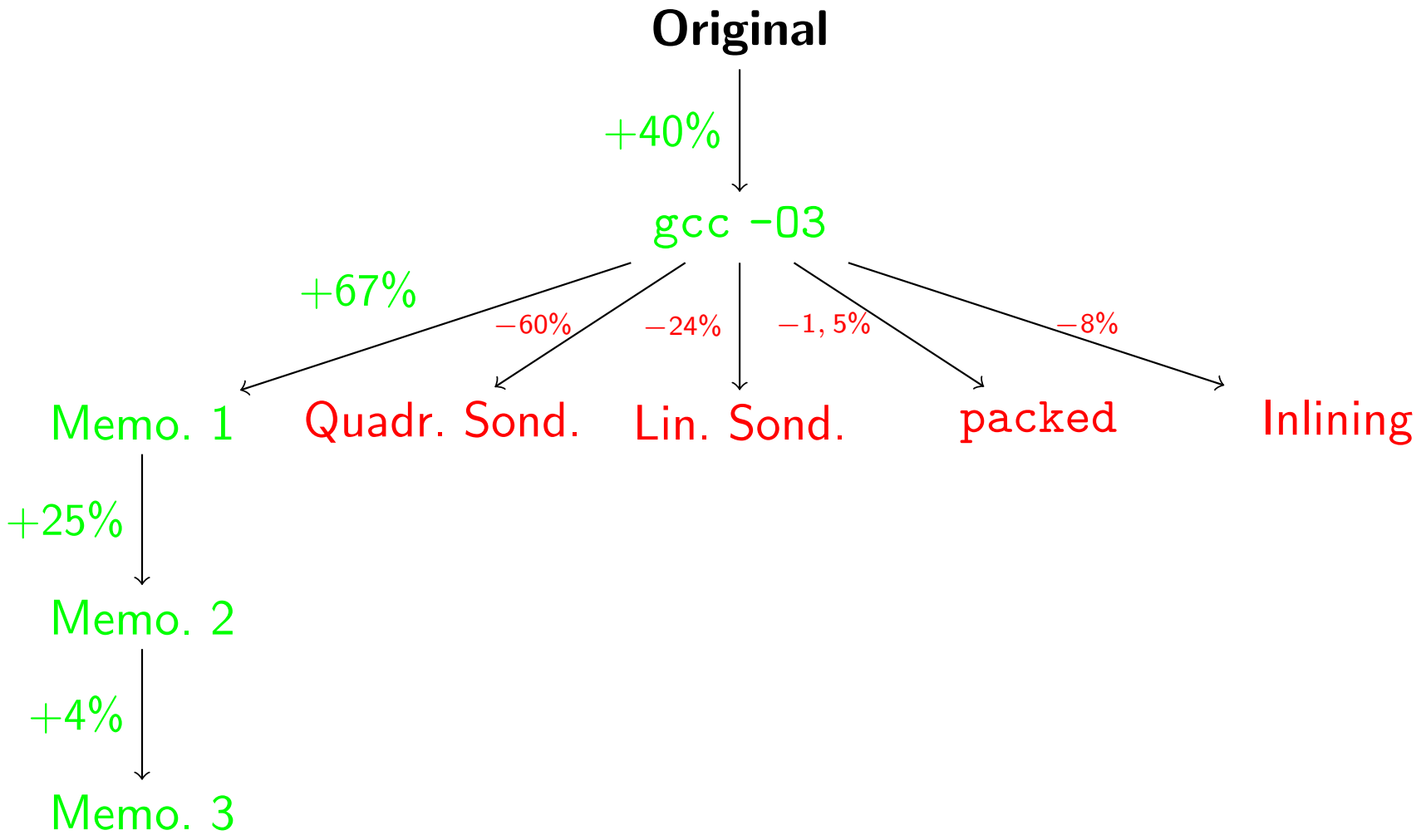
- Cycles: 917,739,423
- Instructions: 702,170,463
- Cache-misses: 4,647,945
- Branch mispredictions: 7,421,590

Nachher:

- Cycles: 879,335,268 ($+4,18\%$)
- Instructions: 701,589,819 ($+0,08\%$)
- Cache-misses: 4,651,776 ($-0,08\%$)
- Branch mispredictions: 7,527,878 ($-1,43\%$)

Verbesserung $\Rightarrow$ beibehalten.

Übersicht


Original
+40%
gcc -O3
+67%
−60%
−24%
−1, 5%
−8%
Memo. 1
Quadr. Sond.
Lin. Sond.
packed
Inlining
+25%
Memo. 2
+4%
Memo. 3

Mathematischer Ansatz

Auflösung von Schleifen und explizite Darstellung

```
for (i=0; i<10; i++) {
    for (p=input2.addr, endp=input2.addr+
        input2.len; p<endp; ) {
        nextp=memchr(p, '\n', endp-p);
        if (nextp == NULL)
            break;
        r = ((unsigned long)r) * 2654435761L +
    lookup(p, nextp-p);
        r = r + (r>>32);
        p = nextp+1;
    }
}
```

Gleiche Berechnung (nur mit anderem Startwert) wird 10 mal durchgeführt.

Mathematischer Ansatz

Auflösung von Schleifen und explizite Darstellung

```
r = ((unsigned long)r) * 2654435761L + lookup(p,
    nextp-p);
r = r + (r>>32);
```

Differenzengleichung 1. Ordnung

$$x_{n+1} = (x_n * 2654435761 + b_n) * (1 + \frac{1}{2^{32}})$$

Mathematischer Ansatz

Auflösung von Schleifen und explizite Darstellung

```
r = ((unsigned long)r) * 2654435761L + lookup(p,
    nextp-p);
r = r + (r>>32);
```

$$x_{n+1} = (x_n * 2654435761 + b_n) * (1 + \frac{1}{2^{32}})$$

$$x_0 = 0$$

$$x_1 = 0 * 2654435761 + b_0 + \frac{x_0 * 2654435761 + b_0}{2^{32}} = b_0 + \frac{b_0}{2^{32}}$$

...

Mathematischer Ansatz

Auflösung von Schleifen und explizite Darstellung

$$x_2 = x_1 * 2654435761 + b_1 + \frac{x_1 * 2654435761 + b_1}{2^{32}}$$

$$x_3 = ((b_0 + \frac{b_0}{2^{32}}) * 2654435761 + b_1 + \frac{x_1 * 2654435761 + b_1}{2^{32}}) * 2654435761 +$$

$$b_2 + \frac{((b_0 + \frac{b_0}{2^{32}}) * 2654435761 + b_1 + \frac{x_1 * 2654435761 + b_1}{2^{32}}) * 2654435761 + b_2}{2^{32}}$$

...

Mathematischer Ansatz

Allgemeine iterative Berechnung von Differenzialglg. 1 Ordnung

vereinfachtes Beispiel:

$$x_{n+1} = x_n * c + b_n$$
$$x_3 = ((x_0 * c + b_0) * c + b_1) * c + b_2$$
$$x_3 = c^3 * x_0 + c^2 * b_0 + c^1 * b_1 + c^0 * b_2$$
$$x_n = c^n * x_0 + \sum_{i=0}^{n-1} c^{n-i-1} * b_i$$

Problematik:

Man hat eine Potenz mit der Anzahl an Iterationen als Hochzahl.
Bsp: input2 hat 724129 Zeilen ber die iteriert wird!