Storage Mapping

Previously

- Tiling
- Spring Break

Today

- Note that Quiz 2 is due by Friday night and your intermediate reports are due next week
- Storage mapping for a 1D stencil computation
- Theory: what form? When legal?
- ScOP for smith waterman and Pluto
- Storage mapping possibilities for smith waterman
- Idea for LCPC paper based on semester projects

1D Stencil Computation Example

Example

```
// assume u[i] initialized to some values
for (s=1; s<T; s+=2) {
  for (i=1; i<(N-1); i++) {
    tmp[i] = 1/3 * (u[i-1] + u[i] + u[i+1]); // S1
  }
 for (j=1; j<(N-1); j++) {
    u[i] = 1/3 * (tmp[j-1] + tmp[j] + tmp[j+1]); // S2
  }
}
```

Analyzing the 1D stencil example

The iteration space …

- For S1
- For S2

How do we embed these in the same space?

- Put j's after i's
- Put j's above i's

How does the code change if it becomes single assignment?

- Do array expansion for both u[] and tmp[]
- Draw pictures of how the arrays are being accessed, notice that there are holes
- How could we rewrite the code to use half of the storage?

Data reuse in the code

Two axes of data reuse

- Temporal and/or spatial
- Value and/or storage reuse

Data reuse within the original computation

- One written value is put into one storage location and used by three computations
  - value and temporal
  - also spatial and storage because value is only stored in one location
- Iteration i+1 reads a shifted set of values from iteration i
  - Value and temporal for the two reads for overlapping inputs
  - Spatial for the reads that are next to each other in memory
- Iteration t+2,i overwrites the same two memory locations as iteration t,i

Ping-Pong compared with a mod mapping

Example (ping-pong)

```
// assume u[i] initialized to some value
for (s=1; s<T; s+=2) {
  for (i=1; i<(N-1); i++) {
    tmp[i] = 1/3 * (u[i-1] + u[i] + u[i+1]); // S1
  }
 for (j=1; j<(N-1); j++) {
    u[i] = 1/3 * (tmp[j-1] + tmp[j] + tmp[j+1]); // S2
  }
}
```

Example (modular mapping) <show how to do this in AlphaZ>

```
// assume u[0][i] initialized to some value
for (s=1; s<T; s++) {
  for (i=1; i<(N-1); i++) {
    u[(t+1)%2][i] = 1/3 * (u[t%2][i-1] + u[t%2][i] + u[t%2][i+1]);
  }
}
```


Storage mapping in general

Specify storage mappings with functions

- For example, write in iteration i,j should be stored in i
- Part of the storage mapping done by compilers is hidden from users
  - Row major
  - Column major

Occupancy vector indicates iterations that share storage

- ov = i-j, then iterations i and j share storage

Determining if a storage mapping is legal

- When a schedule is specified
- For any schedule, universal occupancy vector

Static Control Programs <show smith waterman with PLUTO>

Static Control Programs Definition

- Symbolic constants are variables that are not modified in the loop
- Loop bounds are affine combinations of loop variables and symbolic constants
- Array accesses are affine combinations of loop variables and symbolic constants
- If conditions are affine functions of loop variables and symbolic constants
- All function calls are pure
- In Pluto: change data if conditions to ternary expressions
- In Pluto: min and max are keywords! Do not use them as var names

References

- Pluto_general_notes.txt (see progress web page)
- Pluto/doc/DOC.txt
- Section 2.2 of the Feautrier paper

Storage mapping for smith waterman

What is the output of the computation?

Assume a computation like smith waterman …

- But only the last row of the 2D array is output
- What is a UOV for this data flow pattern?
- What is the corresponding data mapping?
- How can we implement a storage mapping with macros?

LCPC Paper idea

Some LCPC history

Basic outline of the paper

- Survey of the current polyhedral model power
- Case studies that evaluate the current tools based on…
  - Learning curve
  - Ease of use: documentation and robust error messages
  - Amount of tweaking needed to approach "best" possible performance
  - Resulting performance
  - Implementation limitations: what algorithms are not available
- Future research directions

Student semester long projects

Case studies

- Greg: LMie computes the scattering properties for polydisperse homogeneous spherical particles using the Mie solution, POCC
- Jared: Wavelets have become increasingly important in e cient video and image encoding. Pluto
- Glenn: genetic algorithm, POET
- Lixing: embedded applications benchmark, POET
- Matt: nearest neighbor algorithm for data mining, omega
- Brendan: libquantum Shor's algorithm for integer factorization, AlphaZ
- Nirmal: polyhedral benchmark suite, AlphaZ and PLUTO
- Ryan: support vector machine based learning algorithm, omega
- Steve: shortest path, AlphaZ
- Wenxiang: WalLS for solving SAT problems, POCC

Next Time

Lecture

- Transformation review
- Intro to algorithms needed for automation

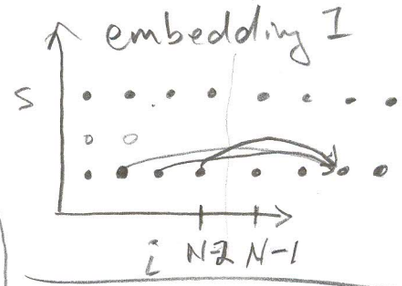
Schedule

- Quiz 2 due March 23rd
- Project intermediate report due March 28th
- April 3rd will be a lab day during class, Manaf will help people with AlphaZ and Pluto. Distance students can email questions or use the discussion board.
- HW6 and HW7 will BOTH be due April 4th

CS 560 3/20/12

```
for (s=1; s<T; s+=2) {
    for (i=1; i<(N-1); i++){
        S1: tmp[i] = 1/3(u[i-1] + ...
    }
    for (j=1; j<(N-1); j++){
        S2: u[i] = 1/3(tmp[i-1]...
    }
}
```

Storage 2N



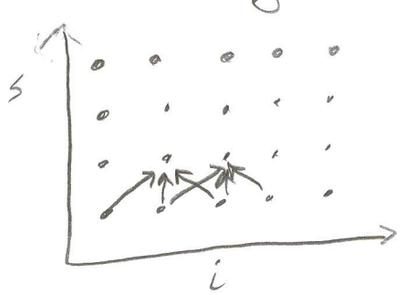
S1 iteration space $\{[s,i] \mid 1 \le s < T \wedge \exists a: 2a+1 = s \wedge 1 \le i \le N-2\}$

S2 iteration space $\{[s,j] \mid$ " " " " " " $\}$
embedding ϕ:

embedding I: $\{[s,i] \mid$ same s constraints $\wedge$ $N-1 \le i \le 2N-4\}$

$$\begin{array}{cc} 1 & N-2 \\ \underline{N-2} & \underline{N-2} \\ N-1 & 2N-4 \end{array}$$

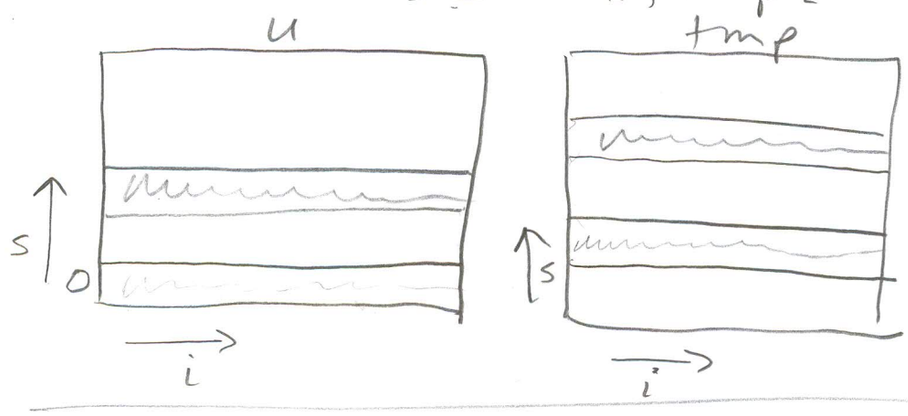
embedding 2: $\{[s,i] \mid 1 \le s \le T \wedge \exists a: 2a = s \; 1 \le i \le N-2\}$



single assignment

```
for (s=1; s≤T; s++) {
    if ( (s-1)%2==0) {                    // ∃a: 2a+1 = s
        for (i=1;
            tmp[s, i] = 1/3*(u[s-1, i] ...
    }
    if ( s%2 == 0 ) {
        for ( i=1;
            u[s, i] = 1/3 *(tmp[s-1, i]
    }
}
```

double u[T+1][N], tmp[T+1][N];



Storage
$2(T+1)N$

```
for (s=1; s≤T; s++) {
    for (i=1; i<(N-1), i++) {
        u[s,i] = 1/3*(u[s-1, i-1] ..
```

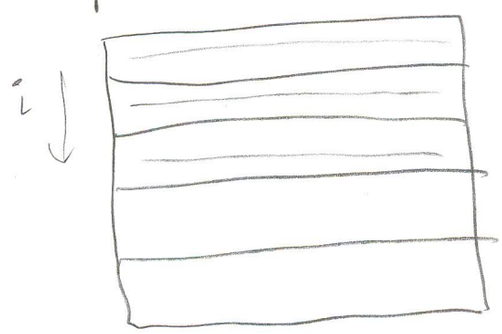
Storage
$(T+1)N$

multidimensional array mappings

$A[i][j]$

double $A[N][M]$

#define $A(i, j)$ $\quad i * M + j$



$A[s_1][s_2]\ldots[s_m]$

row major

#define $A(i_1, i_2, \ldots i_m)$ $\quad i_1 * (s_2 \ldots s_m) + i_2 * (s_3 \ldots s_m) + i_m$

column major

#define $A(i_1, i_2, \ldots i_m)$ $\quad i_m * (s_1 \ldots s_{m-1}) + i_{m-1} * (s_1 \ldots s_{m-2}) + \vdots \; i_1$