CS 701 Final Exam (Reminder)

Thursday, December 11, 11:00 a.m.— 1:00 p.m., in class.

Procedure & Code Placement

We have seen many optimizations that aim to reduce the number of instructions executed by a program.

Another important class of optimizations derives from the fact that programs often must be paged in virtual memory and almost always are far bigger then the I-cache.

Hence how procedures and basic blocks are placed in memory is important. Page faults and I-cache misses can be *very* costly.

In "Profile Guided Code Positioning," Pettis and Hansen explore three kinds of code placement optimizations:

1. Procedure Positioning.

   Try to keep procedures that often call each other close together.

2. Basic Block Positioning.

   Try to place the most frequently executed series of basic blocks "in sequence."

3. Procedure Splitting.

   Place infrequently executed "fluff" in a different memory area than heavily executed code.

Procedure Placement

Procedures (and classes in Java) are normally separately compiled. They are then placed in memory by a linker or loader in an arbitrary order.

This arbitrary ordering can be problematic:

If A calls B frequently, and A and B happen to be placed far apart in memory, the calls will cross page boundaries and perhaps cause I-cache conflicts (if code in A and B happen to map to common cache locations).

However,
if A and B are placed close together in memory, they may both fit on the same page *and* fit into the I-cache without conflicts.

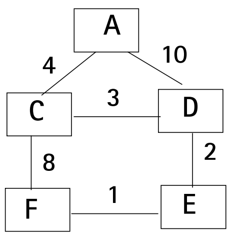
Pettis & Hansen suggest a “closest is best” procedure placement policy.

That is, they recommend that we place procedures that often call each other as close together as possible.

How?

First, we must obtain dynamic call frequencies using a profiling tool like gprof or qpt.

Given call frequencies, we create a call graph, with edges annotated with call frequencies:

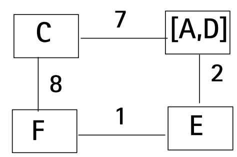


Group Procedures by Call Frequency

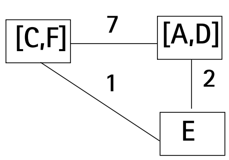
We find the pair of procedures that call each other most often, and group them for contiguous positioning.

The notation [A,D] means A and D will be adjacent (either in order A-D or D-A).

The two procedures chosen are combined in the call graph, which is simplified (much like move-related nodes in an interference graph):



Now C and F are grouped, without their relative order set (as yet):



Next [A,D] and [C,F] are to be joined, but in what exact order?

Four orderings are possible:

A-D-C-F ≡ F-C-D-A

A-D-F-C ≡ C-F-D-A

D-A-C-F ≡ F-C-A-D

D-A-F-C ≡ C-F-A-D

Are these four orderings equivalent?

No—Look at the original call graph. At the boundary between [A,D] and [C,F], which of the following is best:

D-C (3 calls),

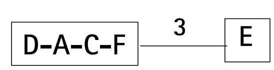
D-F (0 calls)

A-C (4 calls)

A-F (0 calls)

A-C has the highest call frequency, so we choose D-A-C-F.

Finally, we have:



We place E near D (call frequency 2) rather than near F (call frequency 1).

Our final ordering is
E-D-A-C-F.

Basic Block Placement

We often see conditionals of the form

if (error-test)

{Handle error case}

{Rest of Program}

Since error tests rarely succeed (we hope!), the error handling code "pollutes" the I-cache.

In general, we'd like to order basic blocks not in their order of appearance in the source program, but rather in order of their execution along frequently executed paths.

Placing frequently executed basic blocks together in memory fills the I-cache nicely, leads to a smaller working set *and* makes branch prediction easier.

Pettis & Hansen suggest that we profile execution to determine the frequency of inter-block transitions. We then will group blocks together that execute in sequence most often.

At the start, all basic blocks are grouped into singleton chains of one block each.

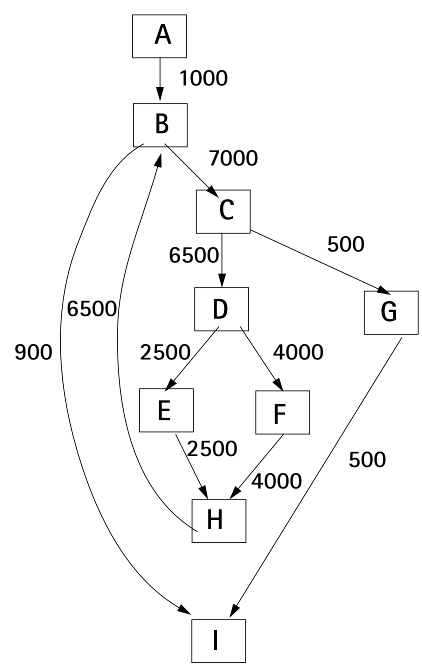
Then, in decreasing order of transition frequency, we visit arcs in the CFG.

If the blocks in the source and target can be linked into a longer chain then do so, else skip to the next transition.

When we are done, we have linked together blocks in paths in the CFG that are most frequently executed.

Linked basic blocks are allocated together in memory, in the sequence listed in the chain.

Example



Initially, each bock is in its own chain.

Frequency	Action
7000	Form B-C
6500	Form B-C-D
6500	Form H-B-C-D
4000	Form H-B-C-D-F
4000	H is already placed
2500	E can't be placed after D, leave it alone
2500	H is already placed
1000	A can't be placed before B, leave it alone
900	I can't be placed after B, leave it alone
500	G can't be placed after C, leave it alone
500	Form G-I

We will place in memory the following chains of basic blocks:

H-B-C-D-F, E, A, G-I

On some computers, the direction of a conditional branch predicts whether the branch is expected to be taken or not (e.g., the HP PA-RISC). On such machines, a backwards branch (forming a loop) is assumed taken; a forward branch is assumed not taken.

If the target architecture makes such assumptions regarding conditional branches, we place chains to (where possible) correctly predict the branch outcome.

Thus E and G-I are placed after H-B-C-D-F since D→E and C→G normally aren't taken.

On the SPARC (V 9) you can set a bit in each conditional branch indicating expected taken/not taken status.

On many machines internal branch prediction hardware can over-rule poorly made (or absent) static predictions.

Procedure Splitting

When we profile the basic blocks within a procedure, we'll see some that are frequently executed, and others that are executed rarely or never.

If we allocate all the blocks of a procedure contiguously, we'll intermix frequently executed blocks with infrequently executed ones.

An alternative is "fluff removal." We can split a procedure's body into two sets of basic blocks: these executed frequently and those executed infrequently (the dividing line is, of course, somewhat arbitrary).

Now when procedure bodies are placed in memory, frequently executed basic blocks will be placed near each other, and infrequently executed blocks will be placed elsewhere (though infrequently executed blocks are still placed near each other). In this way be expect to make better use of page frames and I-cache space, filling them with mostly active basic blocks.