Code Shape I
Procedure Calls & Dispatch

Code Shape

Definition

- All those nebulous properties of the code that impact performance & code "quality"
- Includes code, approach for different constructs, cost, storage requirements & mapping, & choice of operations
- Code shape is the end product of many decisions *(big & small)*

Impact

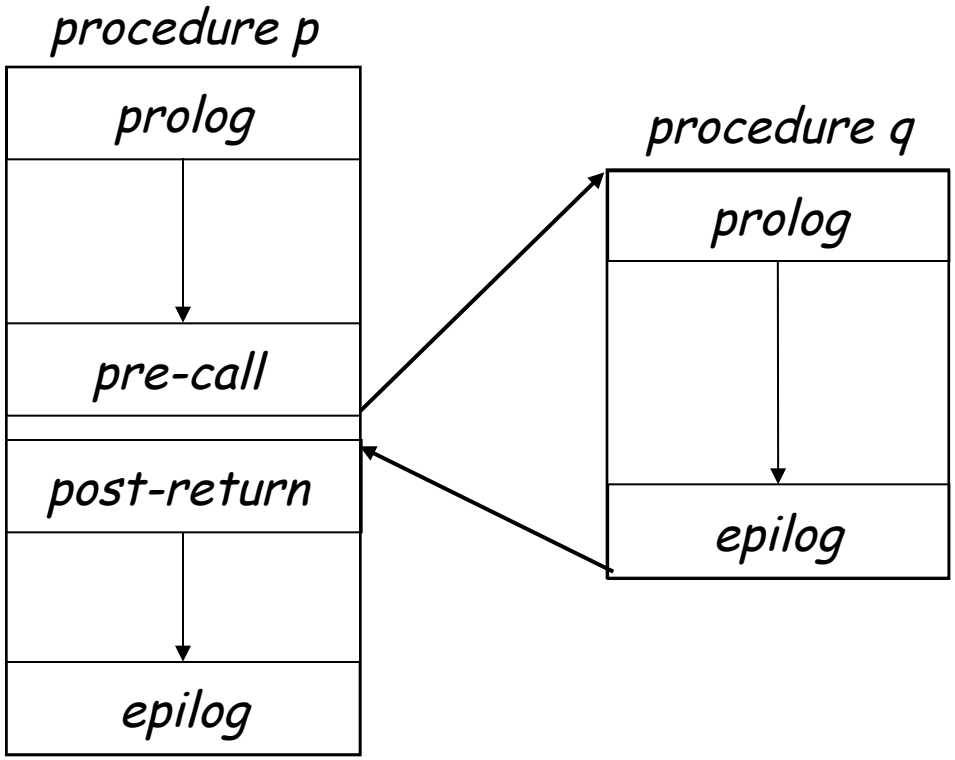
- Code shape influences algorithm choice & results
- Code shape can encode important facts, or hide them

Rule of thumb: expose as much derived information as possible

- Example: explicit branch targets in ILOC simplify analysis
- Example: hierarchy of memory operations in ILOC *(in EaC)*

Procedure Linkages

Standard procedure linkage



Procedure has
- standard prolog
- standard epilog

Each call involves a
- pre-call sequence
- post-return sequence

These are completely predictable from the call site ⇒ depend on the number & type of the actual parameters

Implementing Procedure Calls

If *p* calls *q* …

- In the code for *p*, compiler emits pre-call sequence
  - → Evaluates each parameter & stores it appropriately
  - → Loads the return address from a label
  - → (with access links) sets up *q* 's access link
  - → Branches to the entry of *q*

- In the code for *p*, compiler emits post-return sequence
  - → Copy return value into appropriate location
  - → Free *q* 's AR, if needed
  - → Resume *p* 's execution

Invariant parts of pre-call sequence might be moved into the prolog

Implementing Procedure Calls

If *p* calls *q* …

- In the prolog, *q* must
  - → Set up its execution environment
  - → (with display) update the display entry for its lexical level
  - → Allocate space for its (**AR** &) local variables & initialize them
  - → If *q* calls other procedures, save the return address
  - → Establish addressability for static data area(s)
- In the epilog, *q* must
  - → Store return value (unless "return" statement already did so)
  - → (with display) restore the display entry for its lexical level
  - → Restore the return address (*if saved*)
  - → Begin restoring *p*'s environment
  - → Load return address and branch to it

Implementing Procedure Calls

If *p* calls *q*, one of them must

- Preserve register values (*caller-saves versus callee saves*)
  - → Caller-saves registers stored/restored by *p* in *p*'s AR
  - → Callee-saves registers stored/restored by *q* in *q*'s AR
- Allocate the AR
  - → Heap allocation ⇒ callee allocates its own AR
  - → Stack allocation ⇒ caller & callee cooperate to allocate AR

Space tradeoff

- Pre-call & post-return occur on every call
- Prolog & epilog occur once per procedure
- More calls than procedures
  - → Moving operations into prolog/epilog saves space

Implementing Procedure Calls

If *p* calls *q*, one of them must

- Preserve register values (caller-saves versus callee saves)

If space is an issue

- Moving code to prolog & epilog saves space
- As register sets grow, save/restore code does, too
  - → Each saved register costs 2 operations
  - → Can use a library routine to save/restore
    - ♦ Pass it a mask to determine actions & pointer to space
    - ♦ Hardware support for save/restore or storeM/loadM

Can decouple who saves from what is saved

Implementing Procedure Calls

If *p* calls *q*, one of them must

- Preserve register values (caller-saves versus callee saves)

If space is an issue

- All saves in prolog, all restores in epilog
  - → Caller provides a bit mask for caller-saves registers
  - → Callee provides a bit mask for callee-saves registers
  - → Store all of them in same AR (***either caller or callee***)
  - → Efficient use of time and code space
  - → May waste some register save space in the AR
- Caller-save & callee-save assign responsibility not work

Implementing Procedure Calls

Evaluating parameters

- Call by reference ⇒ evaluate parameter to an lvalue
- Call by value ⇒ evaluate parameter to an rvalue & store it

Aggregates, arrays, & strings are usually c-b-r

- Language definition issues
- Alternative is copying them at each procedure call
  - → Small structures can be passed in registers
  - → Can pass large c-b-v objects c-b-r and copy on modification

AIX does this for C

Implementing Procedure Calls

Evaluating parameters

- Call by reference ⇒ evaluate parameter to an lvalue
- Call by value ⇒ evaluate parameter to an rvalue & store it

Procedure-valued parameters

- Must pass starting address of procedure
- With access links, need the lexical level as well
  - → Procedure value is a tuple ***< level, address >***
    - ♦ May also need shared data areas (*file-level scopes*)
    - ♦ In-file & out-of-file calls have (*slightly*) different costs
  - → This lets the caller set up the appropriate access link

Implementing Procedure Calls

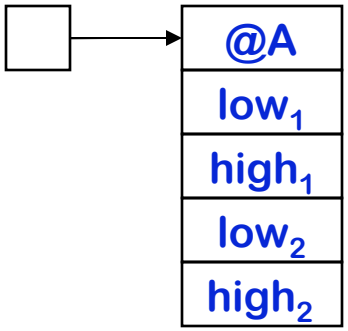
What about arrays as actual parameters?

Whole arrays, as call-by-reference parameters

- Callee needs dimension information ⇒ build a *dope vector*
- Store the values in the calling sequence
- Pass the address of the dope vector in the parameter slot
- Generate complete address polynomial at each reference

Some improvement is possible

- Save len_i and low_i rather than low_i and $high_i$
- Pre-compute the fixed terms in prologue sequence



What about call-by-value?

- Most c-b-v languages pass arrays by reference
- This is a language design issue

Implementing Procedure Calls

What about A[12] as an actual parameter?

If corresponding parameter is a scalar, it's easy

- Pass the address or value, as needed
- Must know about both formal & actual parameter
- Language definition must force this interpretation

What is corresponding parameter is an array?

- Must know about both formal & actual parameter
- Meaning must be well-defined and understood
- Cross-procedural checking of conformability

$\Rightarrow$ Again, we're treading on language design issues

An Aside That Doesn't Fit Well Anywhere …

What about code for access to variable-sized arrays?

Local arrays dimensioned by actual parameters

- Same set of problems as parameter arrays
- Requires dope vectors (or equivalent)
  - → Place dope vector at fixed offset in activation record

⇒ Different access costs for textually similar references

This presents lots of opportunities for a good optimizer

- Common subexpressions in the address polynomial
- Contents of dope vector are fixed during each activation
- Should be able to recover much of the lost ground

⇒ Handle them like parameter arrays

Implementing Procedure Calls

What about a string-valued argument?

- Call by reference ⇒ pass a pointer to the start of the string
  - → Works with either length/contents or null-terminated string
- Call by value ⇒ copy the string & pass it
  - → Can store it in caller's AR or callee's AR
  - → Callee's AR works well with stack-allocated ARs
  - → Can pass by reference & have callee copy it if necessary …

Pointer functions as a "descriptor" for the string, stored in the appropriate location (register or slot in the AR)

Implementing Procedure Calls

What about a structure-valued parameter?

- Again, pass a descriptor
- Call by reference ⇒ descriptor (pointer) refers to original
- Call by value ⇒ create copy & pass its descriptor
  - → Can allocate it in either caller's AR or callee's AR
  - → Callee's AR works well with stack-allocated ARs
  - → Can pass by reference & have callee copy it if necessary …

If it is actually an array of structures, then use a dope vector

If it is an element of an array of structures, then …

What About Calls in an OOL (Dispatch)?

In an OOL, most calls are indirect calls

- Compiled code does not contain address of callee
  - → Finds it by indirection through class' method table
  - → Required to make subclass calls find right methods
  - → Code compiled in class *C* cannot know of subclass methods that override methods in *C* and *C*'s superclasses
- In the general case, need dynamic dispatch
  - → Map method name to a search key
  - → Perform a run-time search through hierarchy
    - ♦ Start with object's class, search for 1st occurrence of key
    - ♦ This can be expensive
  - → Use a method cache to speed search
    - ♦ Cache holds < ***key, class, method pointer*** >

How big?
Bigger ⇒ more hits & longer search
Smaller ⇒ fewer hits, faster search

What About Calls in an OOL (Dispatch)?

Improvements are possible in special cases

- If class has no subclasses, can generate direct call
  - → Class structure must be static or class must be **FINAL**
- If class structure is static
  - → Can generate complete method table for each class
  - → Single indirection through class pointer (***1 or 2 operations***)
  - → Keeps overhead at a low level
- If class structure changes infrequently
  - → Build complete method tables at run time
  - → Initialization & any time class structure changes
- If running program can create new classes, …
  - → Well, not all things can be done quickly

What About Calls in an OOL (Dispatch)?

Unusual issues in OOL call

- Need to pass receiver's object record as (1st) parameter
  - → Becomes self or this
- Typical OOL has lexical scoping in method
  - → Limited to block-style scoping ⇒ no need for access links
  - → Can overlay successive blocks in same method (*reuse*)
- Method needs access to its class
  - → Object record has static pointer to superclass, and so on …
  - → Class pointers don't need updating like access-links
- Method is a full-fledged procedure
  - → It still needs an AR …
  - → Can often stack allocate them (*HotSpot does …*)

What About setjmp() and longjmp() ?

Unix system calls to implement abnormal returns

- Setjmp() stores a descriptor for use with longjmp()
- Invoking longjump(*d*) causes execution to continue at the point after the setjump() call that created *d*

How can we implement setjmp() & longjmp() ?

- Setjmp() must store ARP and return address in descriptor
  - → What about values of registers and variables?
  - → If they are to be preserved, must compute a closure
- Longjmp() must restore environment at setjmp()
  - → Restore ARP & discard ARs creates since setjmp()
    - ◆ Cheap with stack-allocated ARs, might cost more with heap