



COMP 412
FALL 2009

*The Procedure Abstraction:
Parts I & II
Comp 412*

This lecture starts the second major section of the course, which deals with how to implement source language features.

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Conceptual Overview

Procedures provide the fundamental abstractions that make programming useful and practical

- Information hiding
- Distinct and separable name spaces
- Uniform interfaces

Hardware does little to support these abstractions

- Part of the compiler's job is to implement them
 - *Compiler makes good on lies that we tell programmers*
- Part of the compiler's job is to make it efficient
 - *Role of code optimization*



Practical Overview

The compiler must decide almost everything

- Location for each value (named and unnamed)
- Method for computing each result
 - *For example, how should it compute y^x or a case statement?*
- Compile-time versus runtime behavior
- How to locate objects & values created & manipulated by code that the compiler cannot see? (*other files, libraries*)
 - *Dynamic loading and linking add more complications*

All of these issues come together in the implementation of procedures

Pay close attention to compile-time versus runtime

- *Confuses students more than any other issue*



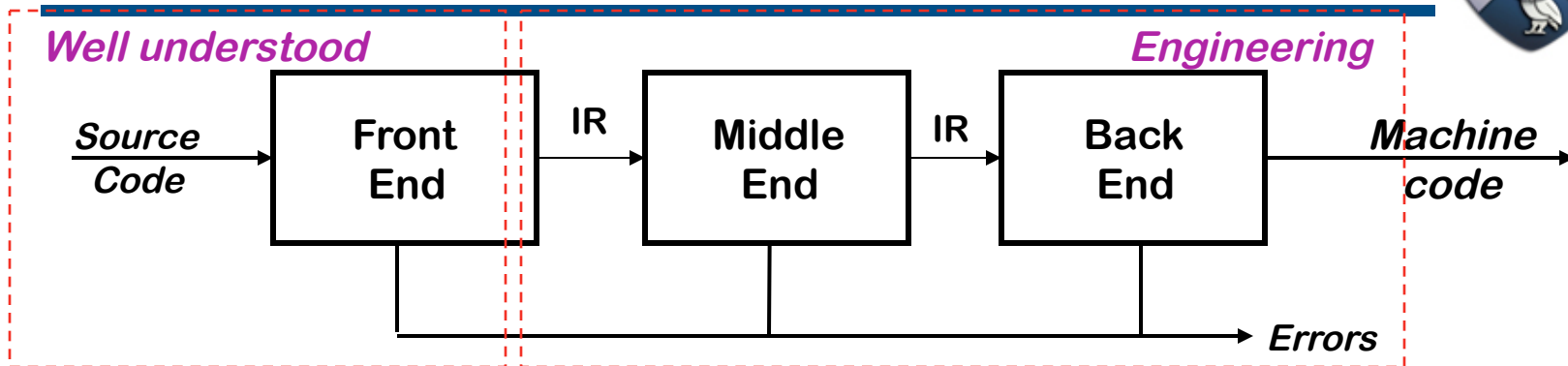
Procedure Abstraction

- Begins Chapter 6 in EAC
- The compiler must deal with interface between **compile time** and **run time** ("static" versus "dynamic")
 - Most of the tricky issues arise in implementing "procedures"

Issues

- Compile-time versus run-time behavior
- Assign storage for EVERYTHING, & map names to addresses
- Generate code to compute addresses that the compiler cannot know!
- Interfaces with other programs, other languages, & the OS
- Efficiency of implementation

Where are we?



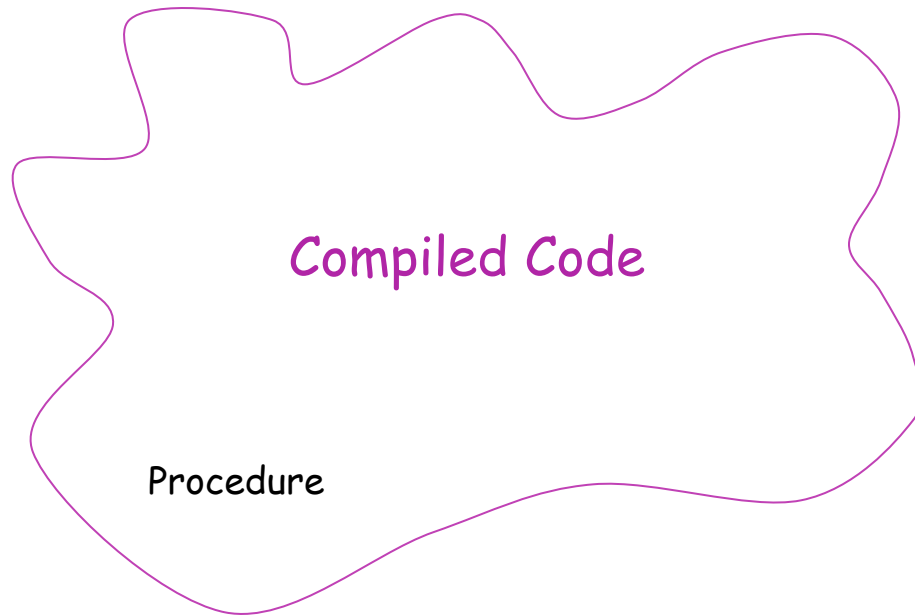
The latter half of a compiler contains more open problems, more challenges, and more gray areas than the front half

- This is “compilation,” as opposed to “parsing” or “translation”
- Implementing promised behavior
 - Defining and preserving the **meaning** of the program
- Managing target machine resources
 - Registers, memory, issue slots, locality, power, ...
 - These issues determine the **quality** of the compiled code



The Procedure & Its Three Abstractions

The compiler produces code for each procedure

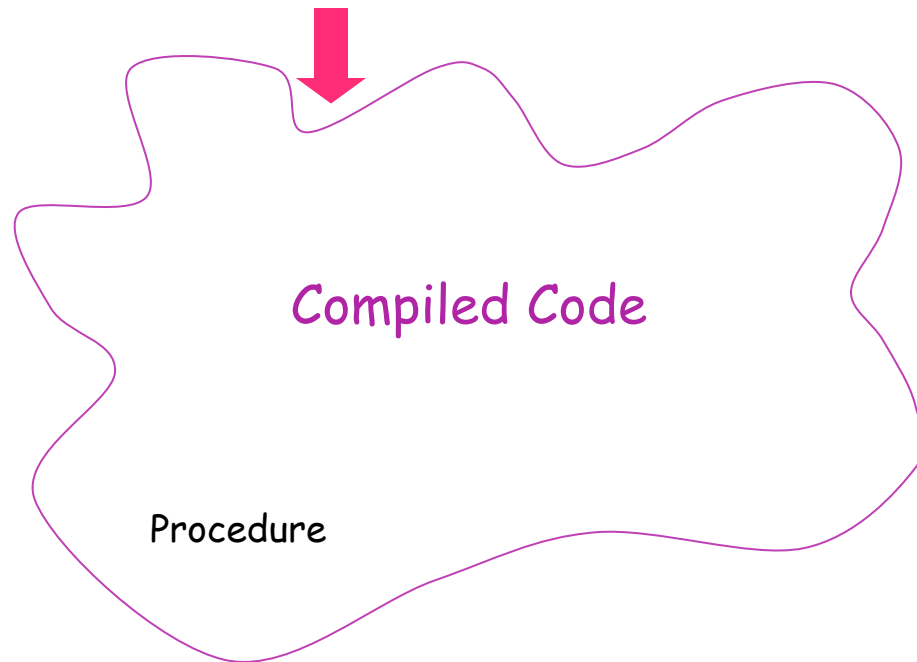


The individual code bodies must fit together to form a working program

The Procedure & Its Three Abstractions



Naming Environment



"Naming" includes the ability to find and access objects in memory

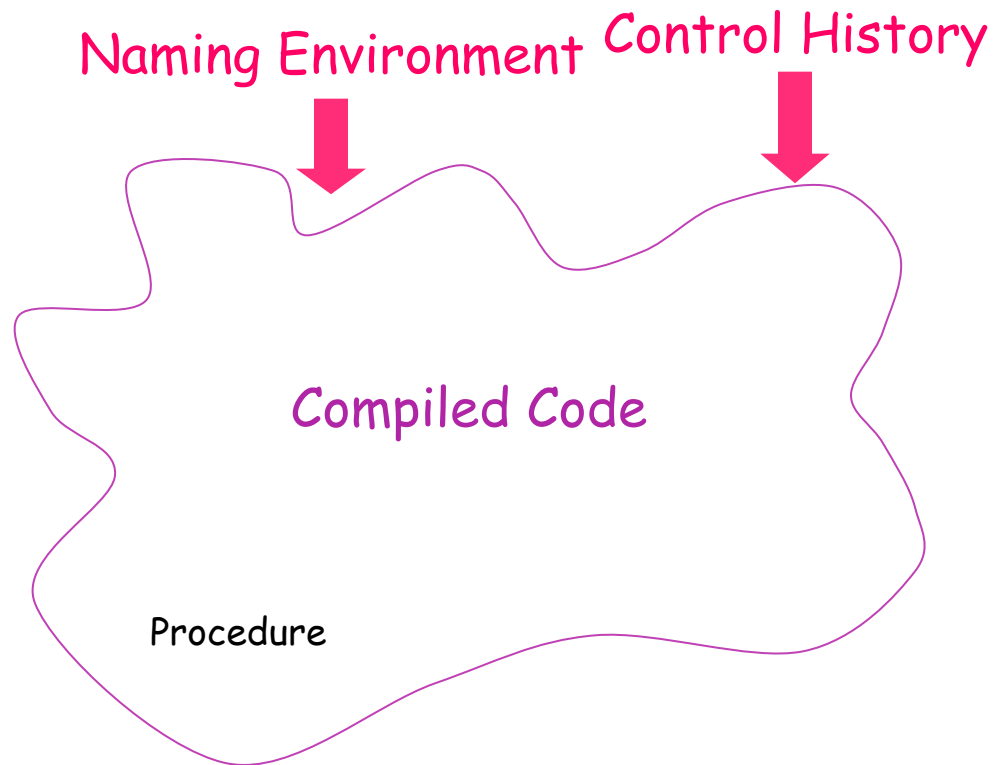
Each procedure inherits a set of names

⇒ Variables, values, procedures, objects, locations, ...

⇒ Clean slate for new names, "scoping" can hide other names



The Procedure & Its Three Abstractions



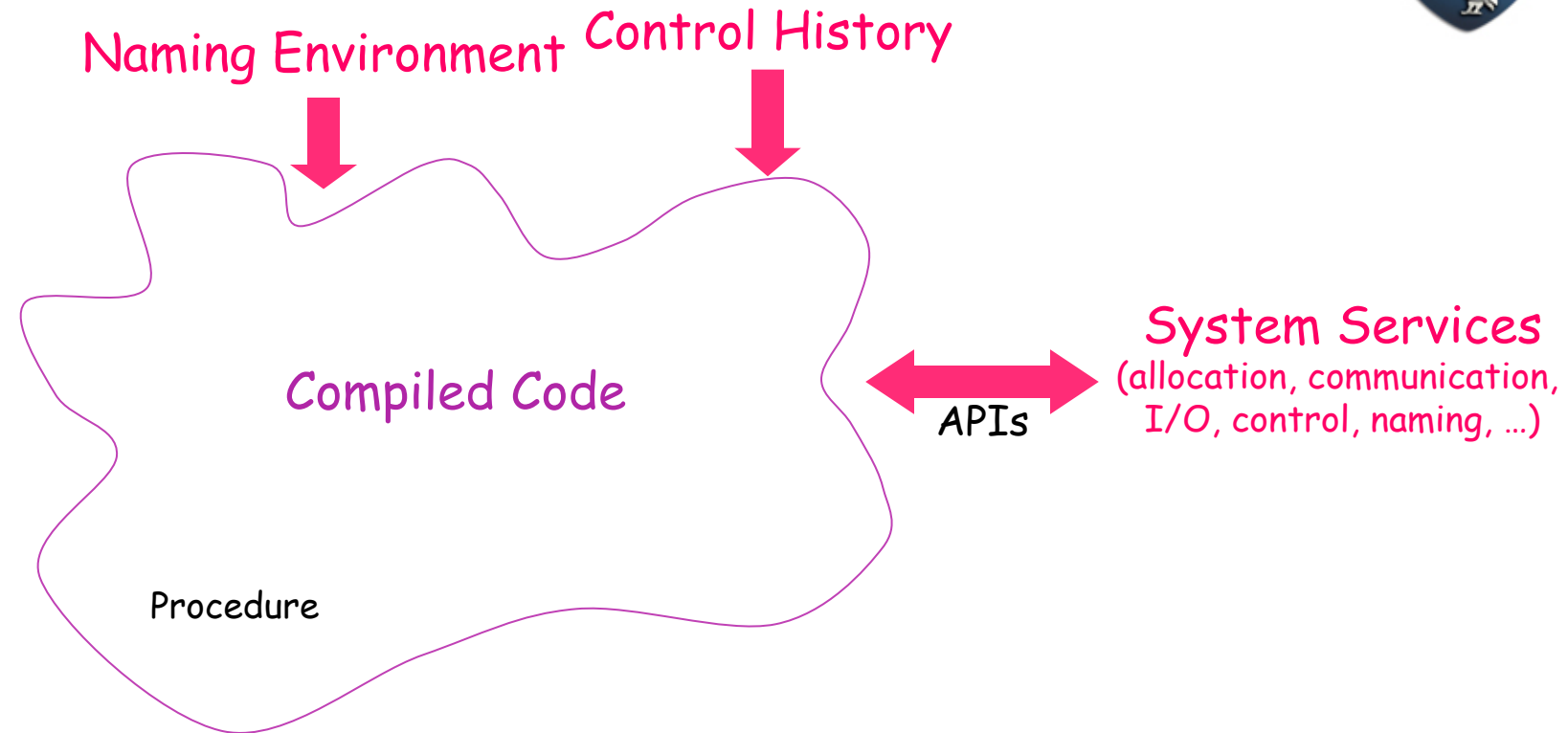
Each procedure inherits a control history

⇒ Chain of calls that led to its invocation

⇒ Mechanism to return control to caller

} Some notion of parameterization (ties back to naming)

The Procedure & Its Three Abstractions



Each procedure has access to external interfaces

⇒ Access by name, with parameters *(may include dynamic link & load)*

⇒ Protection for both sides of the interface



The Procedure: Three Abstractions

- **Control** Abstraction
 - Well defined entries & exits
 - Mechanism to return control to caller
 - Some notion of parameterization (usually)
- **Clean Name Space**
 - Clean slate for writing locally visible names
 - Local names may obscure identical, non-local names
 - Local names cannot be seen outside
- **External Interface**
 - Access is by procedure name & parameters
 - Clear protection for both caller & callee
 - Invoked procedure can ignore calling context

Procedures permit a critical separation of concerns

The Procedure

(Realist's View)



Procedures are the key to building large systems

- Requires **system-wide compact**
 - Conventions on memory layout, protection, resource allocation calling sequences, & error handling
 - Must involve architecture (ISA), OS, & compiler
- Provides shared **access to system-wide facilities**
 - Storage management, flow of control, interrupts
 - Interface to input/output devices, protection facilities, timers, synchronization flags, counters, ...
- Establishes a **private context**
 - Create private storage for each procedure invocation
 - Encapsulate information about control flow & data abstractions

The Procedure

(Realist's View)



Procedures allow us to use **separate compilation**

- Separate compilation allows us to build non-trivial programs
- Keeps compile times reasonable
- Lets multiple programmers collaborate
- Requires independent procedures

Without separate compilation, we *would not* build large systems

The procedure **linkage convention**

- Ensures that each procedure inherits a valid run-time environment and that the callers environment is restored on return
 - The compiler must generate code to ensure this happens according to conventions established by the system

The Procedure

(More Abstract View)



A procedure is an abstract structure constructed via software

Underlying hardware directly supports little of the abstraction—it understands bits, bytes, integers, reals, & addresses, but not:

- **Entries** and **exits**
- **Interfaces**
- **Call** and **return** mechanisms
 - may be a special instruction to save context at point of call
- **Name space**
- **Nested scopes**

All these are established by a carefully-crafted system of mechanisms provided by compiler, run-time system, linkage editor and loader, and OS



Run Time versus Compile Time

These concepts are often confusing to the newcomer

- Linkages (*and code for procedure body*) execute at **run time**
- Code for the linkage is emitted at **compile time**
- The linkage is designed long before either of these

This issue (compile time versus run time) confuses students more than any other issue in Comp 412

- We will emphasize the distinction between them

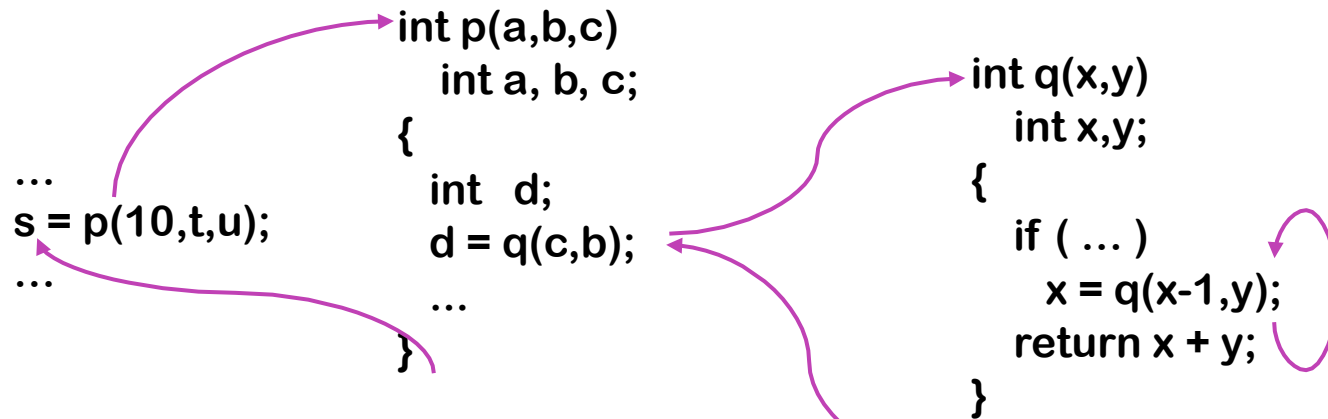


The Procedure as a Control Abstraction

Procedures have well-defined control-flow

The Algol-60 procedure call

- Invoked at a call site, with some set of *actual parameters*
- Control returns to call site, immediately after invocation



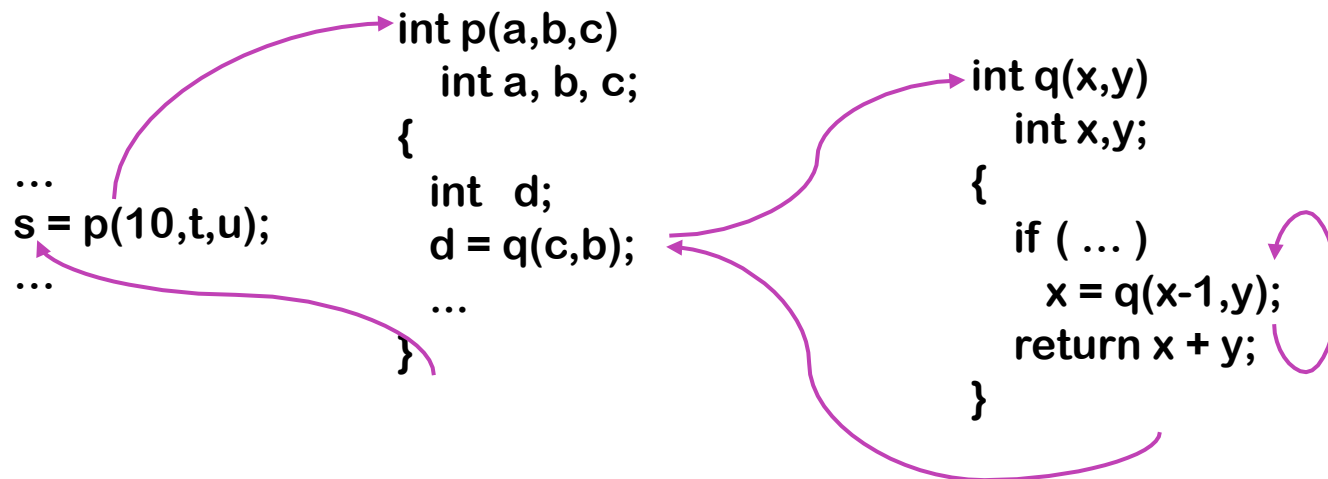
- Most languages allow recursion



The Procedure as a Control Abstraction

Implementing procedures with this behavior

- Requires code to **save** and **restore** a "return address"
- Must map **actual parameters** to **formal parameters** ($c \rightarrow x, b \rightarrow y$)
- Must create storage for **local variables** (& maybe, parameters)
 - p needs space for d (& maybe, $a, b,$ & c)
 - where does this space go in recursive invocations?



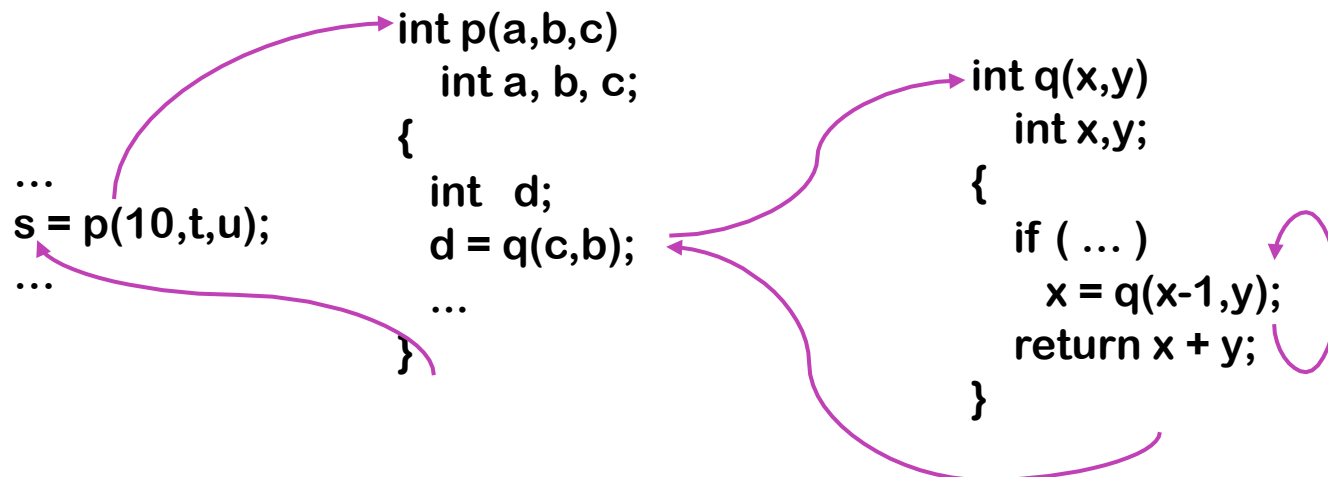
Compiler emits code that causes all this to happen at run time



The Procedure as a Control Abstraction

Implementing procedures with this behavior

- Must preserve *p*'s **state** while *q* executes
 - recursion causes the real problem here
- *Strategy*: Create unique location for each procedure **activation**
 - In simple situations, can use a "stack" of memory blocks to hold local storage and return addresses (*closures* \Rightarrow *heap allocate*)

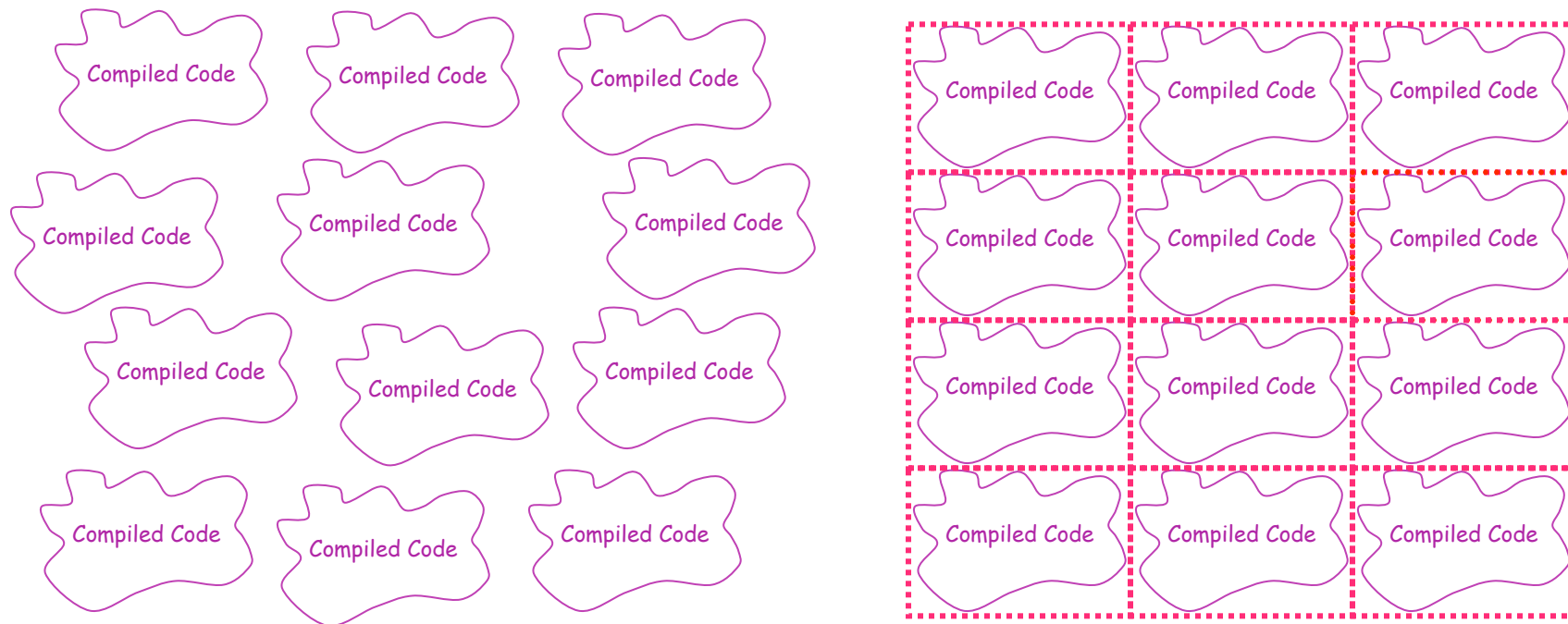


Compiler emits code that causes all this to happen at run time



The Procedure as a Control Abstraction

In essence, the procedure linkage wraps around the unique code of each procedure to give it a uniform interface



Similar to building a brick wall rather than a rock wall