A Framework for Binary Code Analysis, and Static and Dynamic Patching

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Motivation

- Binary code analysis is a basic tool of security analysts, application developers, system designers and tool developers.
- Existing binary analysis tools have significant limitations.
- We are designing and building a new foundation to support such analysis.
  - Multi-platform
  - Open architecture
  - Extensible
  - Open source
  - Testable
  - Suitable for batch processing
  - Accurate
  - Efficient

Why Binary Code?

- Access to the source code often is not possible:
  - Proprietary software packages.
  - Stripped executables.
  - Proprietary libraries: communication (MPI, PVM), linear algebra (NGA), database query (SQL libraries).
- Binary code is the only authoritative version of the program.
  - Changes occurring in the compile, optimize and link steps can create non-trivial semantic differences from the source and binary.
- Worms and viruses are rarely provided with source code

Our Starting Point: Dyninst

- A machine-independent library for machine level code patching.
  - Functions for binary code analysis
  - Functions for binary code patching
- Clean abstractions to encapsulate the tool complexity.
- Originally designed as part of the Paradyn performance profiling tool, but now widely used in many areas, including cyber-security.

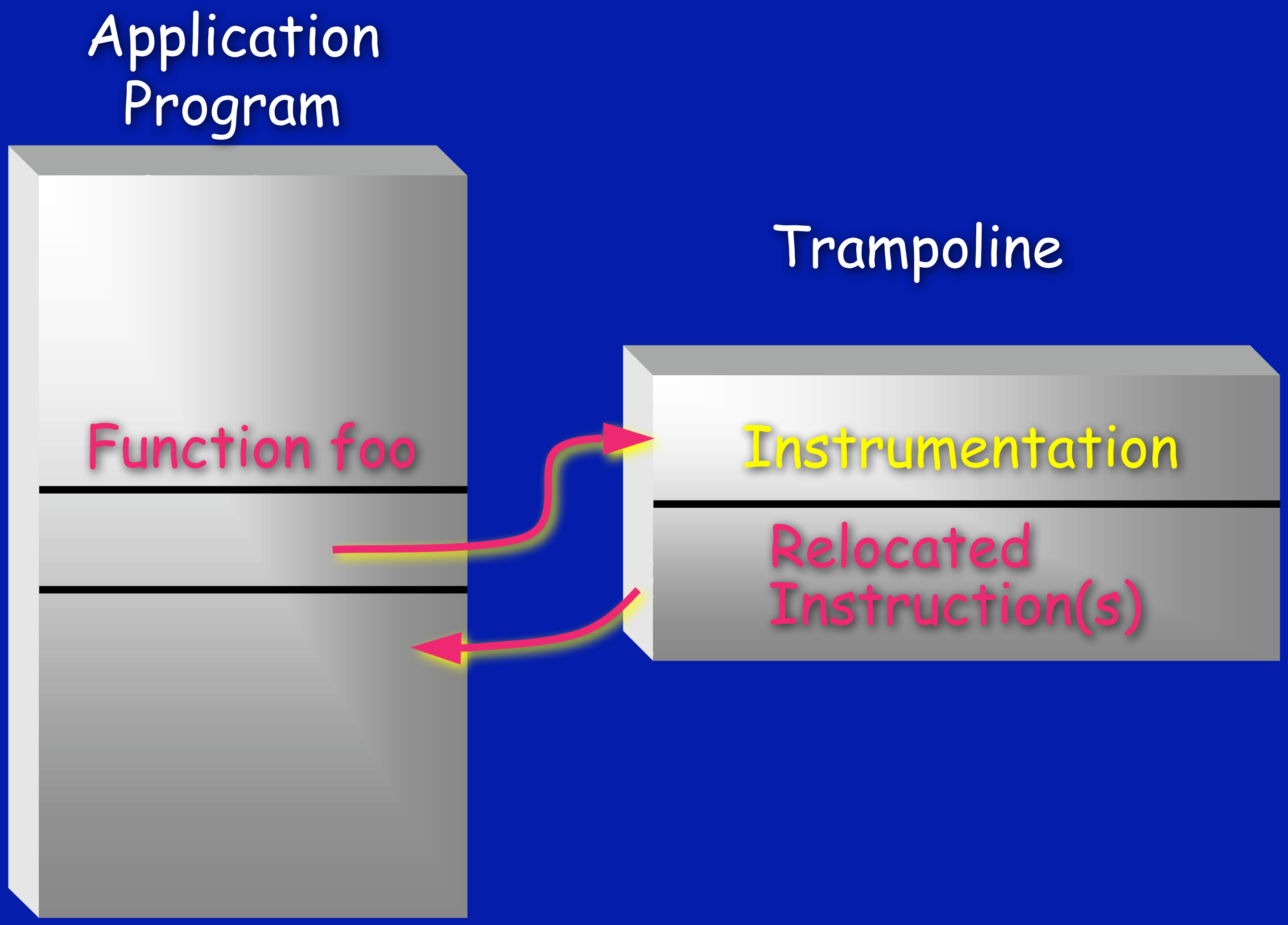
Dynamic Instrumentation

- Does not require recompiling or relinking
  - Saves time: compile and link times are significant in real systems.
  - Can instrument without the source code (e.g., proprietary libraries).
  - Can instrument without linking (relinking is not always possible.
- Instrument optimized code.

Dynamic Instrumentation (con'd)

- Only instrument what you need, when you need
  - No hidden cost of latent instrumentation.
  - Enables "one pass" tools.
- Can instrument running programs (such as Web or database servers)
  - Production systems.
  - Embedded systems.
  - Systems with complex start-up procedures.

The Basic Mechanism



The DynInst Interface

- Machine independent representation
- Write-once, analyze/instrument-many (portable)
- Object-based interface to insert new code: Abstract Syntax Trees (AST's)
- Hides most of the complexity in the API
  - Easy to build tools: e.g., an MPI tracer: 250 lines of C++ code.

Basic DynInst Operations

- Code query routines:
  - Find control-flow elements: modules, procedures, loops, basic blocks, instructions
    - For functions, find entry, exit, call sites.
    - For loops, find entry, exit, body.
  - Find data elements: variables and parameters
  - Call graph (parent/child) queries
  - Intra-procedural control-flow graph

Basic DynInst Operations

- Code modification routines:
  - Remove Function Call
    - Disable an existing function call in the application
  - Replace Function Call
    - Redirect a function call to a new function
  - Replace Function
    - Redirect all calls (current and future) to a function to a new function.
  - Replace Instruction
    - Code snippet executes instead of specified instruction.
  - Wrap Function
    - Allow the new function to call the replaced one (potentially with all its original parameters).

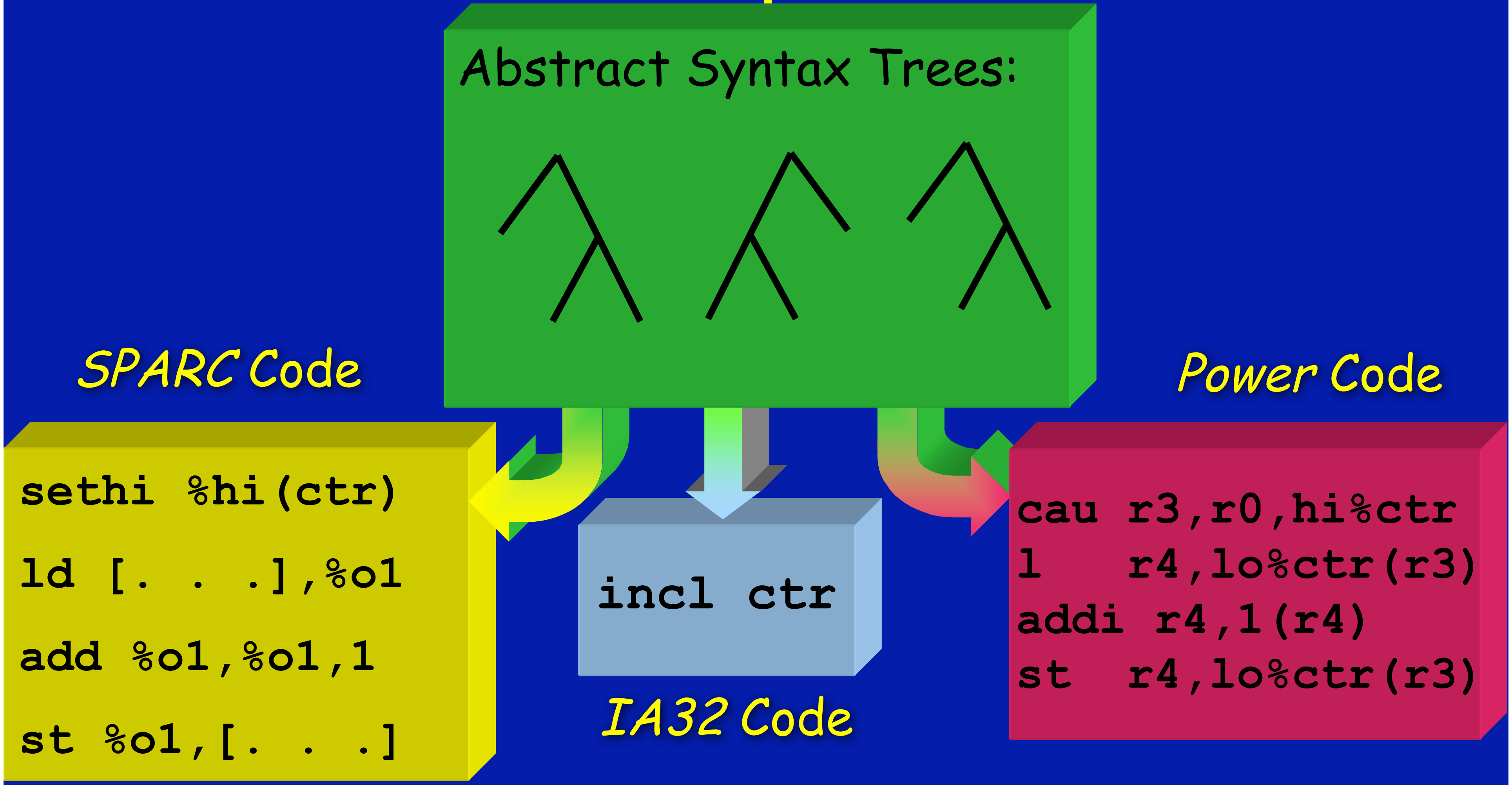
Basic DynInst Operations

- Process control:
  - *Attach/create process*
  - *Monitor process status changes*
  - *Callbacks for fork/exec/exit*
- Inferior (application processor) operations:
  - *Malloc/free*
    - Allocate heap space in application process
  - *Inferior RPC*
    - Asynchronously execute a function in the application.
  - *Load module*
    - Cause a new .so/.dll to be loaded into the application.

Basic DynInst Operations

- Building AST code sequences:
  - Control structures: if and goto
  - Arithmetic and Boolean expressions
  - Get effective address
  - Generate instruction with calculated address.
  - Get PID/TID operations
  - Read/write registers and global variables
  - Read/write parameters and return value
  - Function call

Machine Independent Code



SPARC Code

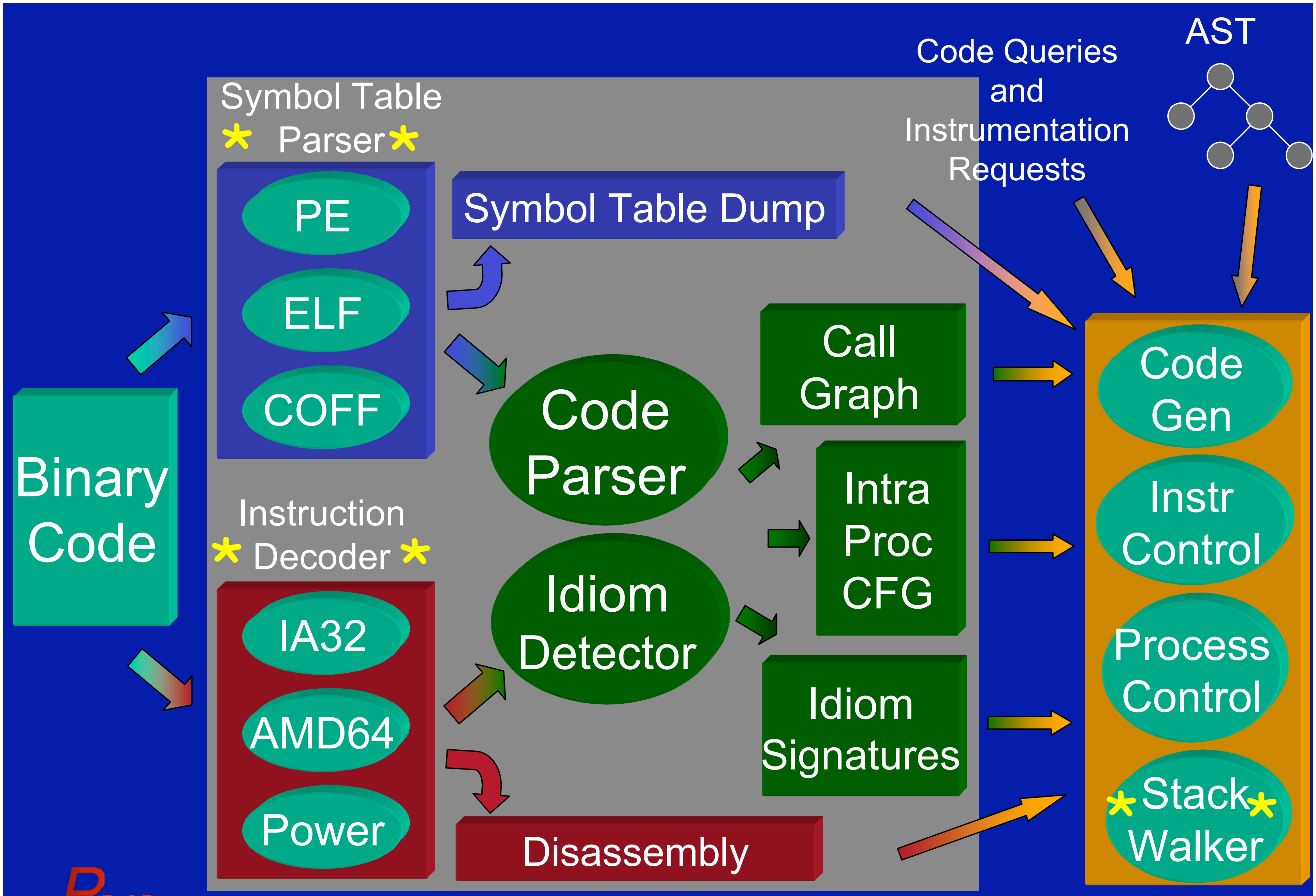
```
sethi %hi(ctr)
ld [. . .],%o1
add %o1,%o1,1
st %o1,[. . .]
```

IA32 Code

```
incl ctr
```

Power Code

```
cau r3,r0,hi%ctr
l   r4,lo%ctr(r3)
addi r4,1(r4)
st  r4,lo%ctr(r3)
```


Binary Code
Symbol Table
* Parser *
PE
ELF
COFF
Symbol Table Dump
Instruction
* Decoder *
IA32
AMD64
Power
Disassembly
Code Parser
Idiom Detector
Call Graph
Intra Proc CFG
Idiom Signatures
Code Queries and Instrumentation Requests
AST
Code Gen
Instr Control
Process Control
* Stack * Walker

SymtabAPI

- Version 1.0 available as of June 5, 2007.
  - Supports ELF, XCoff, PE (Linux, Solaris, AIX, Windows).
- Debug information available in next release: line numbers, local variables, types.
- Unstrip - SymtabAPI demo tool that regenerates a stripped binary's symbol table
  - Uses code parser to find function entry points
  - Uses SymtabAPI to write new symbol table into binary.

DynStackwalker

- Available soon on all Dyninst platforms.
- Cross-platform API for collecting first and third party stackwalks.
- Callback interface allows users to plug in their own stack walking mechanisms, e.g:
  - Walking through non-standard stack frames created by optimized functions.
  - Use stackwalking debug information provided by another library

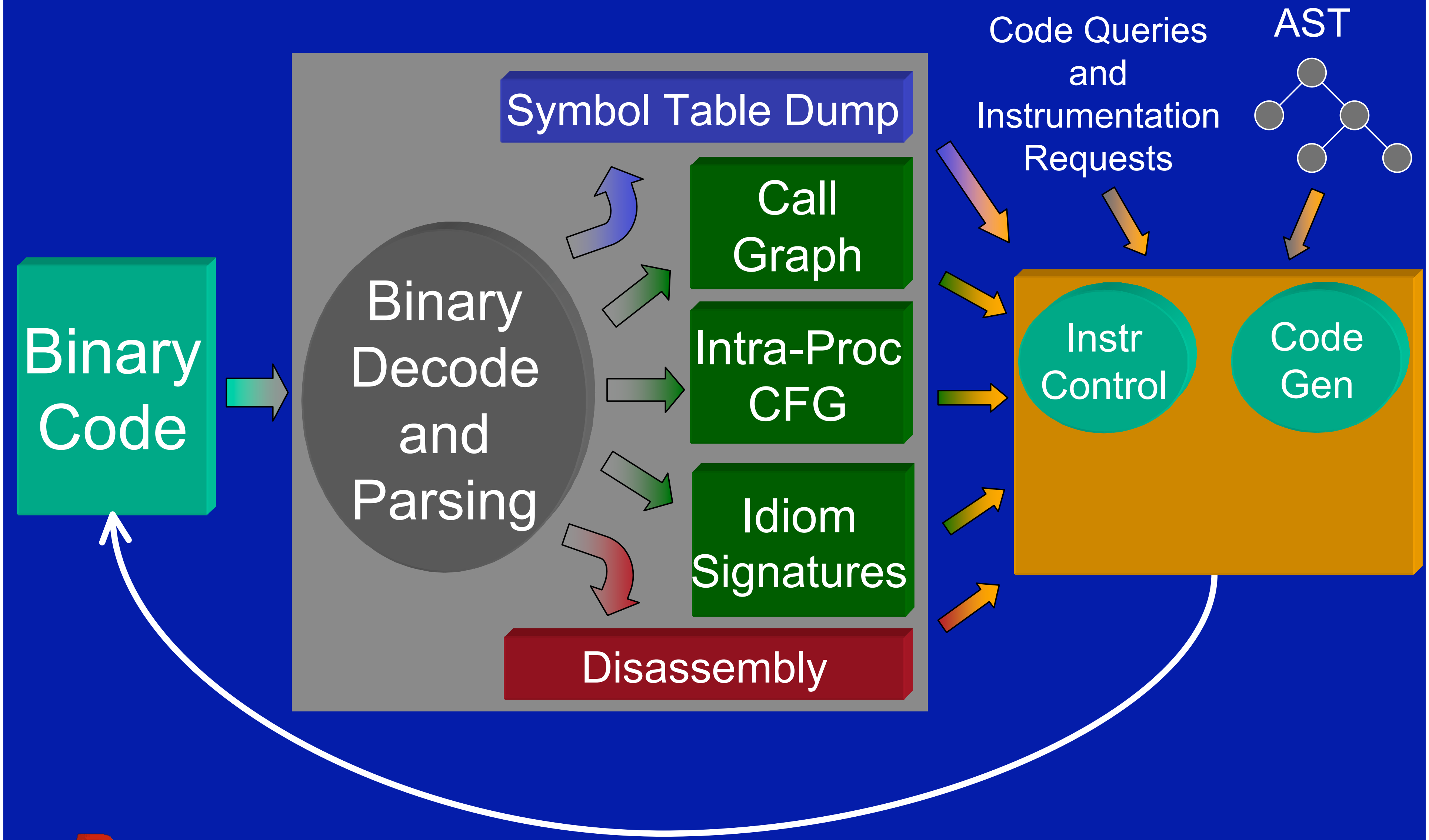
InstructionAPI

- Decodes machine code into abstract instruction representation
- Interface allows straightforward data flow and control flow analysis
  - Query interface is designed for analysis, e.g.:
    - Control flow targets
    - Registers read/written
    - Memory addresses accessed
  - Instructions can be annotated with analysis results
- Provides disassembly interface
  - Pluggable formatters

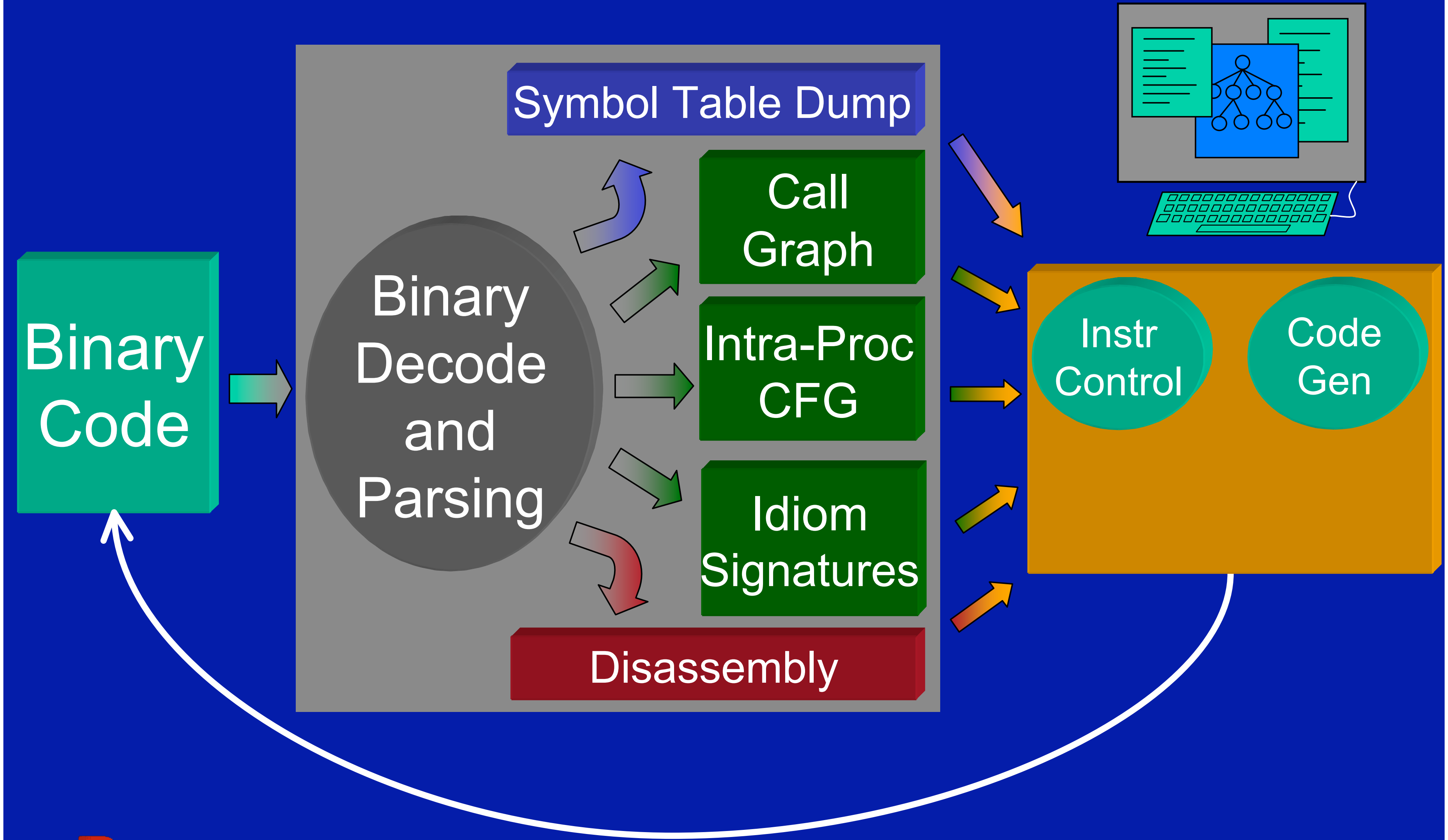
BinInst Design Goals

- Tool-kit component architecture for binary analysis and editing
- Open source
- Open data structure definitions
- Machine-independent abstract interfaces
- Batch-enabled analyses
- Static and dynamic code patching
- All major analysis products are exportable
- Enhanced testability and accompanying test suites

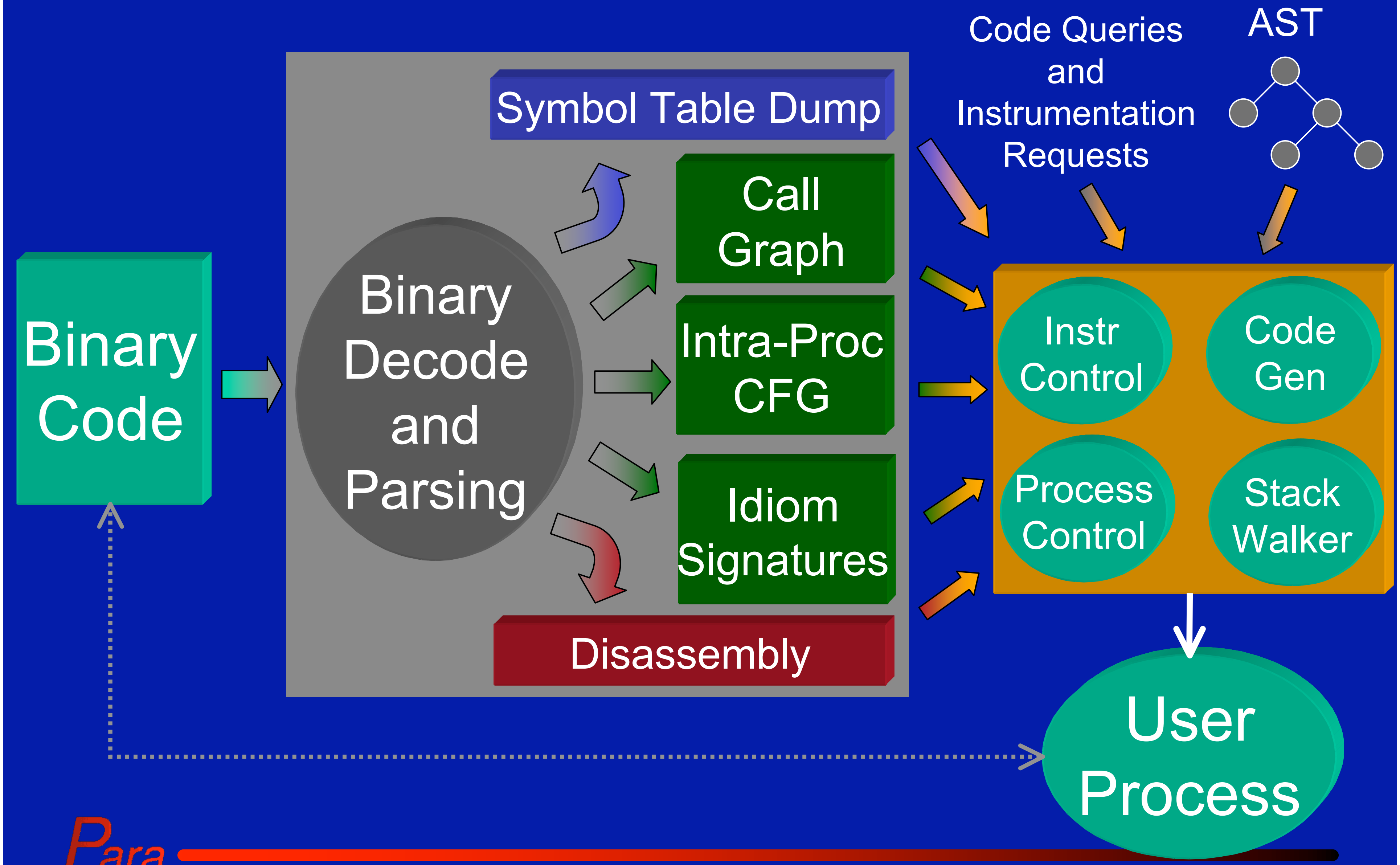
Static Editing Scenario (*Binary Rewriting*)



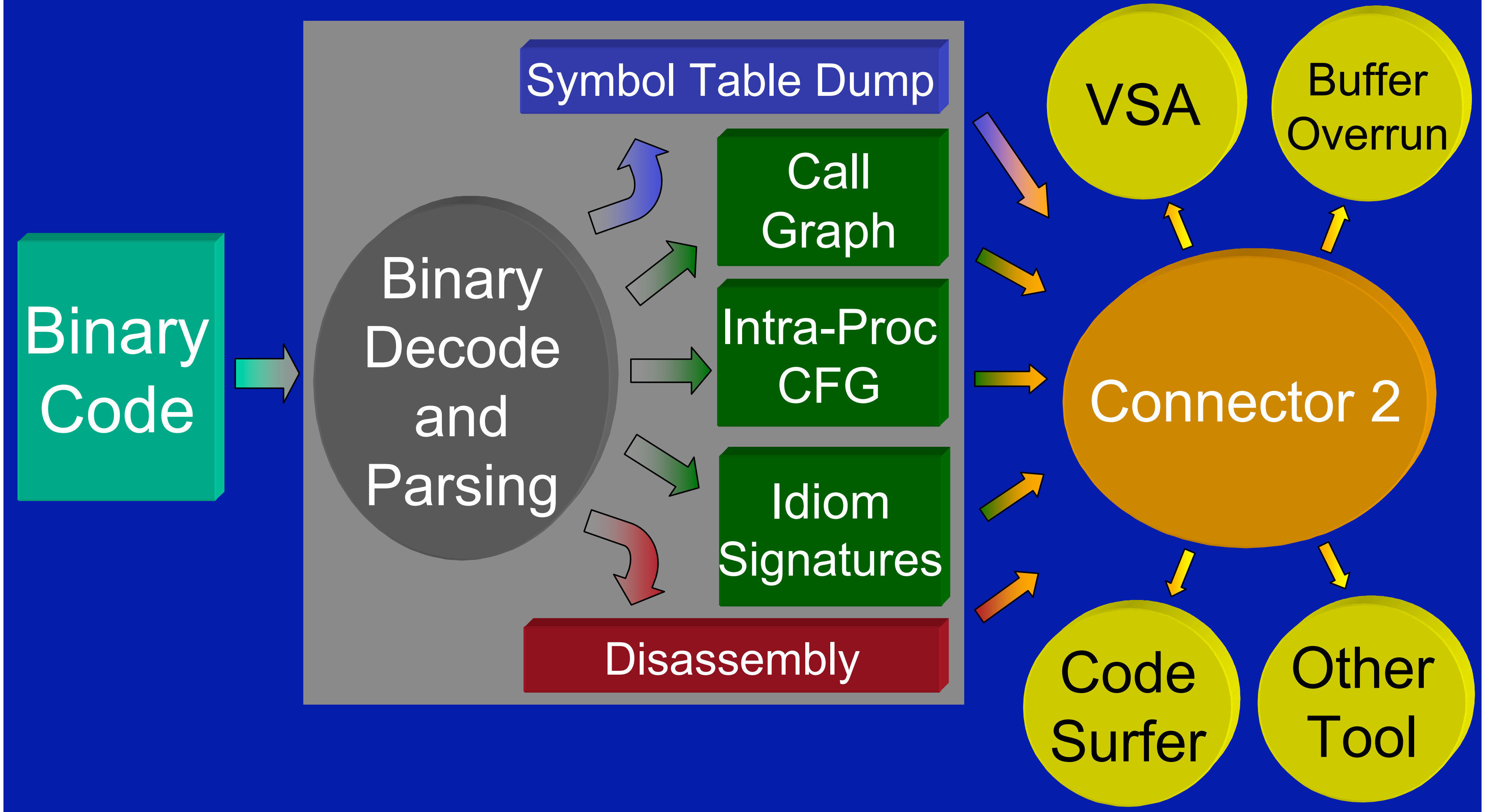
Interactive Editing Scenario (Static or Dynamic)



Dynamic Editing Scenario (*Dynamic Instrumentation*)



Analysis Scenario


Binary Code
Binary Decode and Parsing
Symbol Table Dump
Call Graph
Intra-Proc CFG
Idiom Signatures
Disassembly
Connector 2
VSA
Buffer Overrun
Code Surfer
Other Tool