# Hardware-based Control Flow Monitoring to Prevent Malicious Control Flow Redirection

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# Outline

- Introduction
  - Motivation for hardware-based approach
  - Targeted security problems
  - Expected benefits of dynamic hardware based approach
- Hardware-Based Control Flow Monitoring
  - Conceptual Architecture Model
  - Leveraging Indirect Branch Prediction Mechanism
- Preliminary Results
- Open Questions

# Current Approaches

- Flawfinder , ITS4, and RATS: Source Code Inspection
- Stackguard, ProPolice: Compiler Extension
- Libsafe: Library Call Monitoring
- Converting Static Array memory allocation to Dynamic Heap memory Allocation

# Why Revisiting Code is Not Enough

- Source Code Unavailability
  - Legacy Application
  - Third Party Integration
- If Source Code is Available
  - Requires Diverse Programming Language Support
  - Operating Environment Support
  - Tractability of Static Approaches: Swamped with Analysis Data
- Zero Day Attack: With only static analysis support protection is not possible
- Missing Software Updates, Simultaneous Existence of Multiple Versions

# Control Flow Redirection

- Stack Smashing
- Heap Exploits
- Format String Exploits

Exploits that allow attacker to overwrite any random bytes in the memory!!

# Benefits of Hardware-based Approach

- Code that is executing needs to be analyzed
  - Extraneous code is not exposed so can be filtered
  - Fast execution
- All applications supported by hardware are supported
  - No language dependency
  - No operating system dependency
- Malicious behavior is caught immediately
  - Supports Zero Day Exploits
  - No need to update the system
  - Multiple versions of software can exist in the system with equal security support

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# Hardware Based Control Flow Monitoring

```
if ( i > 10)
  a = b;
else
  a = c;
```

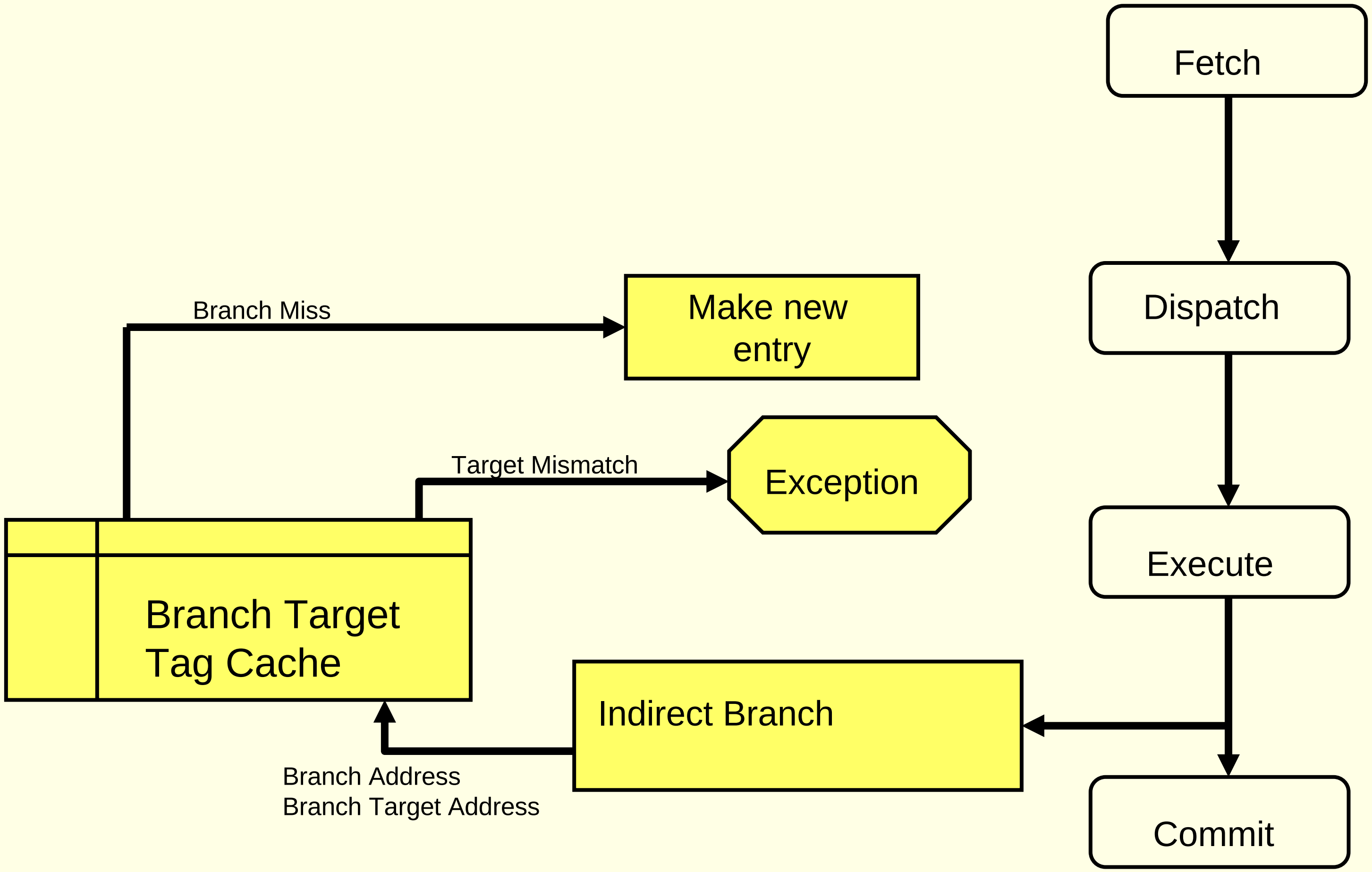
```
strcpy(a,b);
return;
```

```
fptr= pt2fun;
 char *a, *b;
strcpy(a,b);
fptr();
```

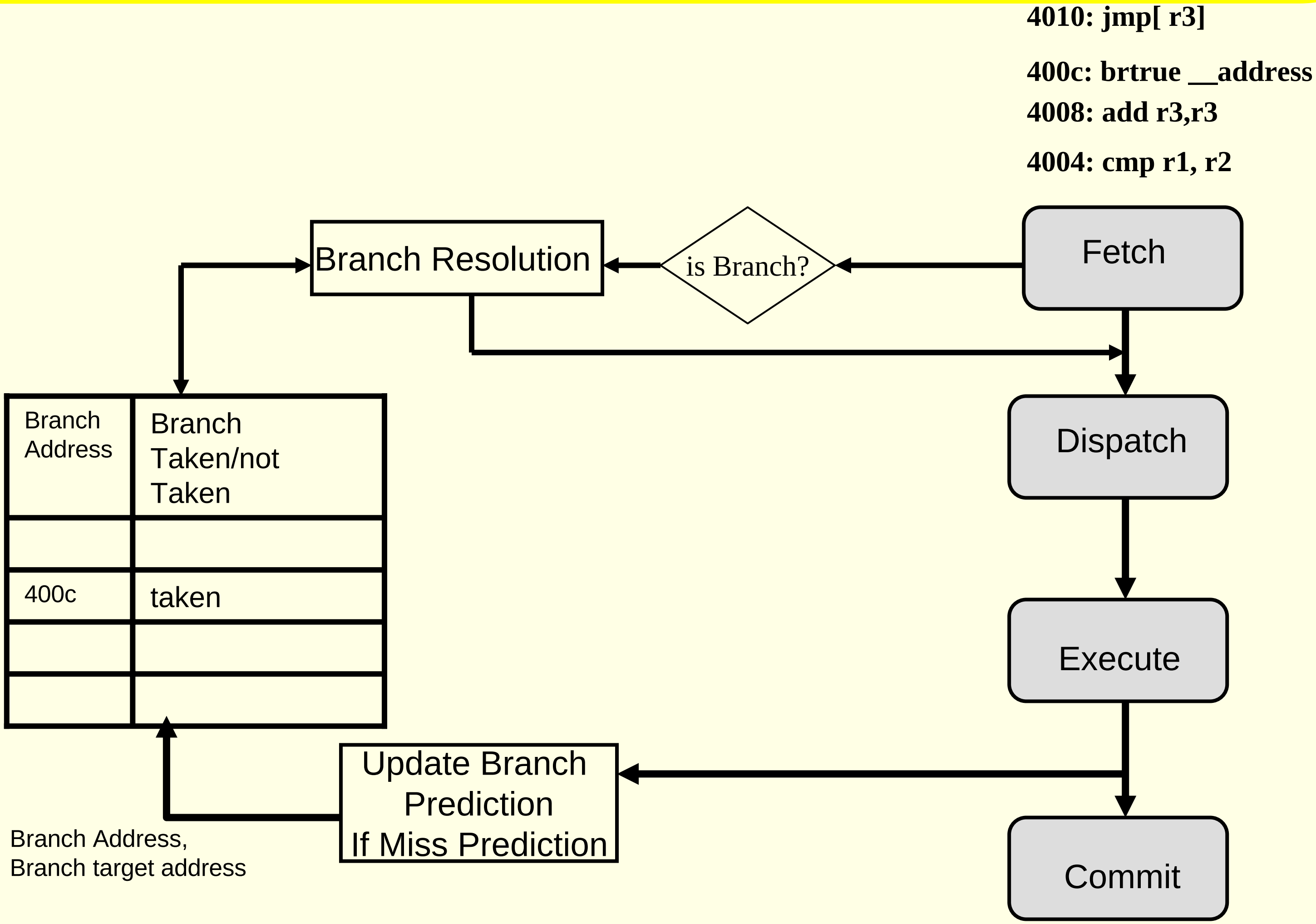
# Hardware Based Control Flow Monitoring

- Only branches that compute their target address (Indirect Branches) can be exploited
- Examples:
  - Function pointers (e.g., C++ vtables, callbacks for dynamic binding)
  - Return addresses
  - Global Offset Table for dynamic library linking
  - DTORS section for storing constructor/destructor address
- We model indirect branch targets and monitor them for change in behavior

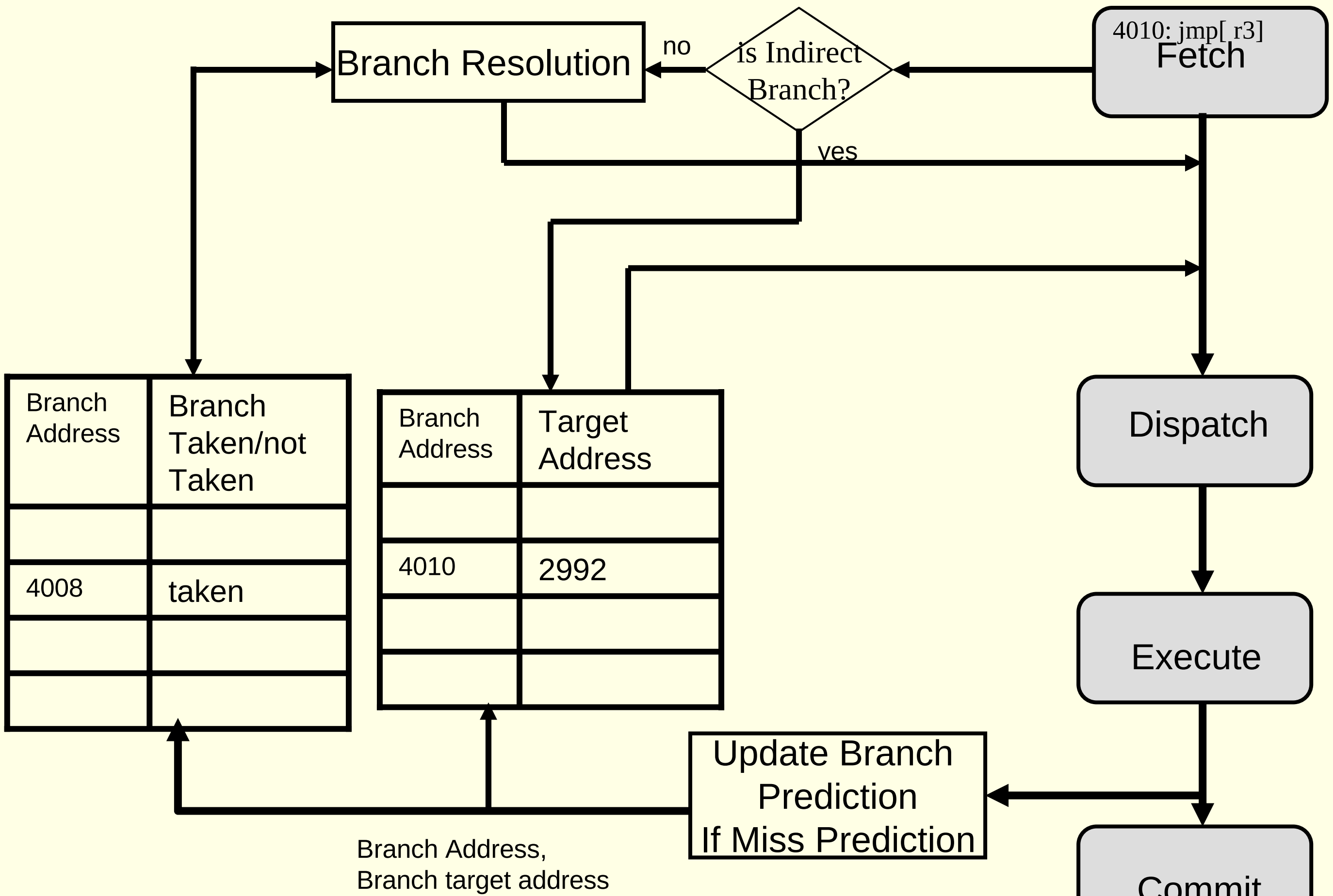
# Conceptual Architecture View



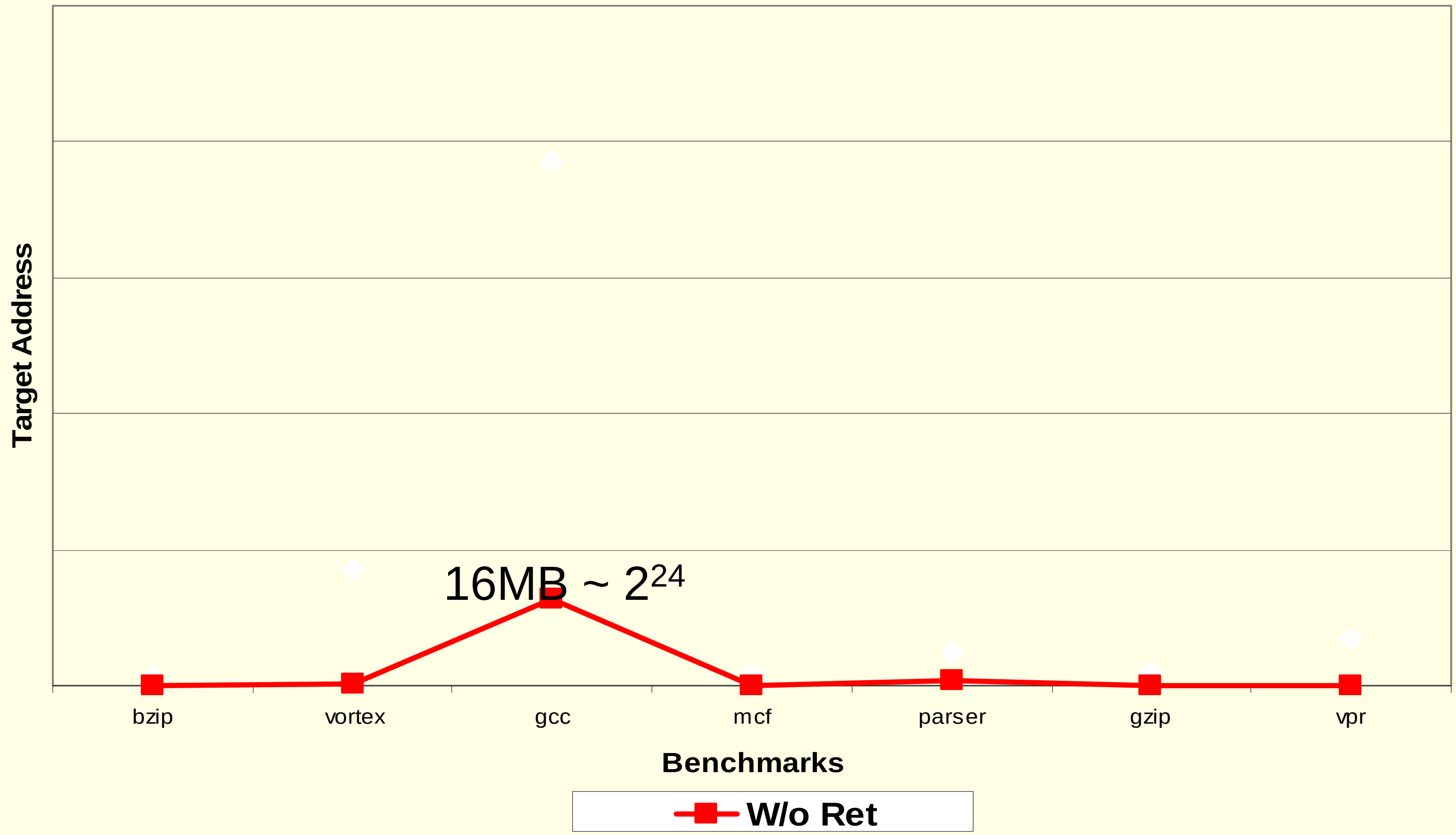
# Branch Prediction



# Branch Prediction



# Relative Branch Target Address Range Distribution-Spec2000 Benchmarks



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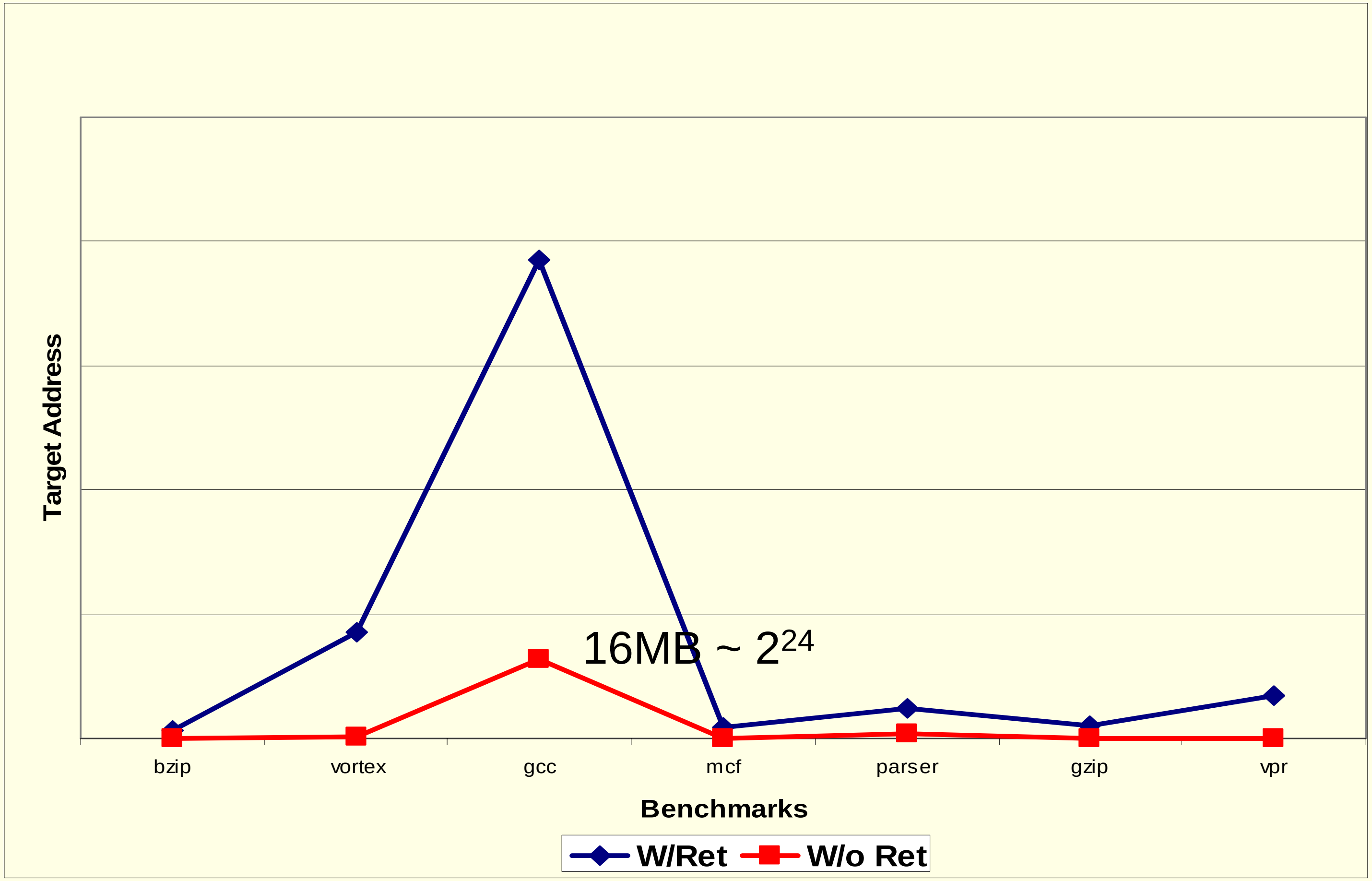
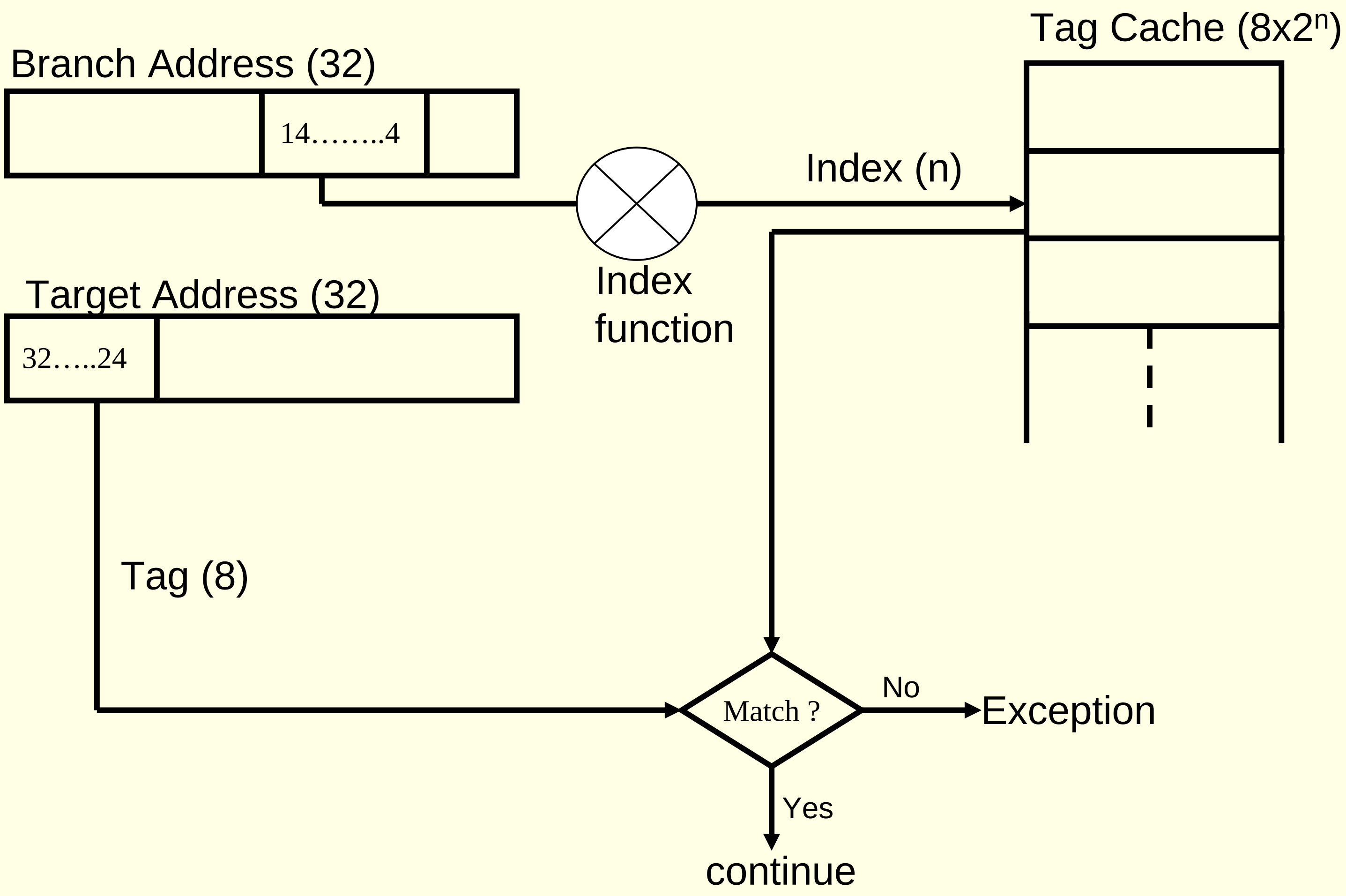
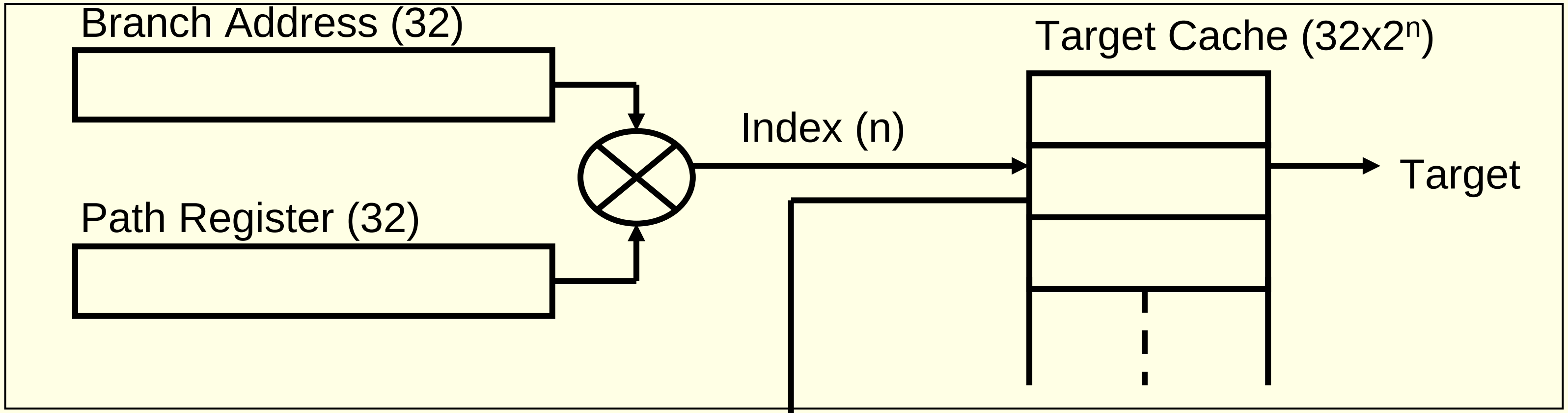


# Tag Comparator to Detect Malicious Control Flow Redirection

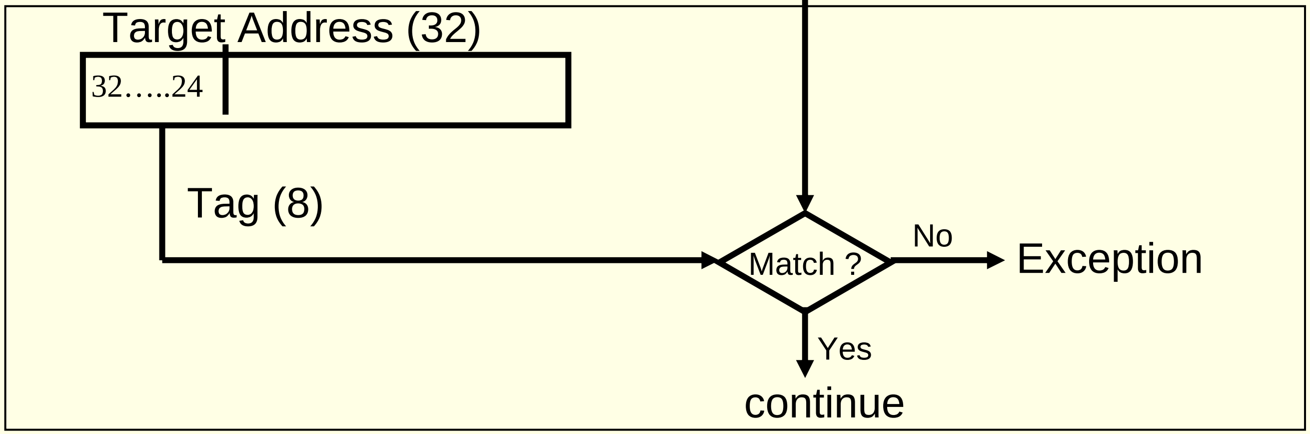


# Extension to Indirect Branch Prediction for Malicious Control Flow Redirection

**Indirect Branch Prediction Hardware**




**Additional Logic for Malicious Control Flow**



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# Simulation Environment

- Simics® x86 Simulator from VirtueTech
- Linux Operating System
- Test Cases
  - WU-FTP : Format String
  - Home Brewed EchoServer : String Buffer Overflow

# Wu-FTP Vulnerability

```
void vreply(long flags, int n, char *fmt, va_list ap)
{
 char buf[BUFSIZE];
 flags &=USE_REPLY_NOTFMT |
USE_REPLY_LONG;
If(n)
      sprintf(buf, "%03d%c"
 n,flags & USE_REPLY_LONG? '-': ':');
      snprintf(buf+(n ? 4 : 0),n ? Sizeof(buf) – 4:
sizeof(buf), "%s" , fmt);
Else
     vsnprintf(buf+(n ? 4 : 0), n? sizeof(buf) –
4 : sizeof(buf), fmt , ap);.

if (debuf)
     syslog( LOG_DEBUF, "< ---- %s", buf);
     printf("%s \r\n",buf);
.. .... .. . .

}
```

Step 1: objdump –R /usr/sbin/in.ftpd (Reverse engineer program binary to see GOT table from in assembly format)

```
.......
083b9213      R_386_JUMP_SLOT printf
----------
```

Step 2: anonymous connect to wu-ftp server

Step 3: send malicious string to print parameters on the stack and deternine where the string that attacker (here we) send is located

Step 4: send malicious string to overwrite printf address

Suppose the string that we send start at parameter 272 on the stack then send string containing:

1) Number of characters equal to address of the malicious code followed by,
2) Address of the printf function entry in GOT table

e.g.
"%.4000$'**\x13\x92\3b\08**%272$s'"

# Preliminary Results

- Echoserver: Buffer overflow exploited to overwrite a function pointer on the function stack: successfully caught
- Wu-FTP Format String Vulnerability Exploited to Overwrite a Global Offset Table (GOT) Entry
  - GOT is used for Dynamic library linking, widely used software technique for third party share

# Open Issues

- Extension to RISC architecture
- Support for applications that are passive in nature

# Acknowledgement


- EASL Group, Georgia Institute of Technology
- National Science Foundation
  - Grant CCR-0092552 & CCR-0209179