Polyglot: Automatic Extraction of Protocol Message Format using Dynamic Binary Analysis

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Protocol reverse-engineering

- **Process of extracting the application-level protocol used by a program, without access to the protocol specification**
- **Encompasses extracting:**
  - **the** Protocol Message Format
  - **the** Protocol State Machine
- **Challenges:**
  - **No protocol specification**
    - » **Many closed application protocols**
  - **Automatic**
    - » **Samba, ICQ, Yahoo Messenger took years**

This paper is about the Protocol Message Format

Outline

- **Introduction**
- **Techniques**
  - **Direction field extraction**
  - **Separator extraction**
  - **Keyword extraction**
  - **Multi-byte fixed length fields**
- **Evaluation**

Automatic message format extraction

- **Extract the Protocol Message Format, one message at a time**
- **Problem: Automatically extract the message format from an unknown message given a program binary implementing the protocol**
- **Message Format = field sequence**
  - **Field: smallest contiguous sequence of application data with meaning**

Use dynamic binary analysis to extract message format

Message Format Applications

- **Extracting the message format is important for multiple problems:**
  - **Protocol analyzers**
  - **Application dialog replay**
  - **Intrusion detection**
  - **Fingerprint generation**
  - **Detecting services running on non-standard ports**

Challenges

Main challenge is to identify the field boundaries:

1. Variable-length fields **boundaries**
   - **Extract the** direction fields **(e.g. length fields)**
   - **Extract the** separators
2. Fixed-length fields **boundaries**
   - **Avoid concatenating two consecutive fields**
   - **Avoid splitting a single field into multiple ones**

Another important challenge is to:

3. **Find the** keywords **present in the message**
   - **Allow to map traffic to the protocol**

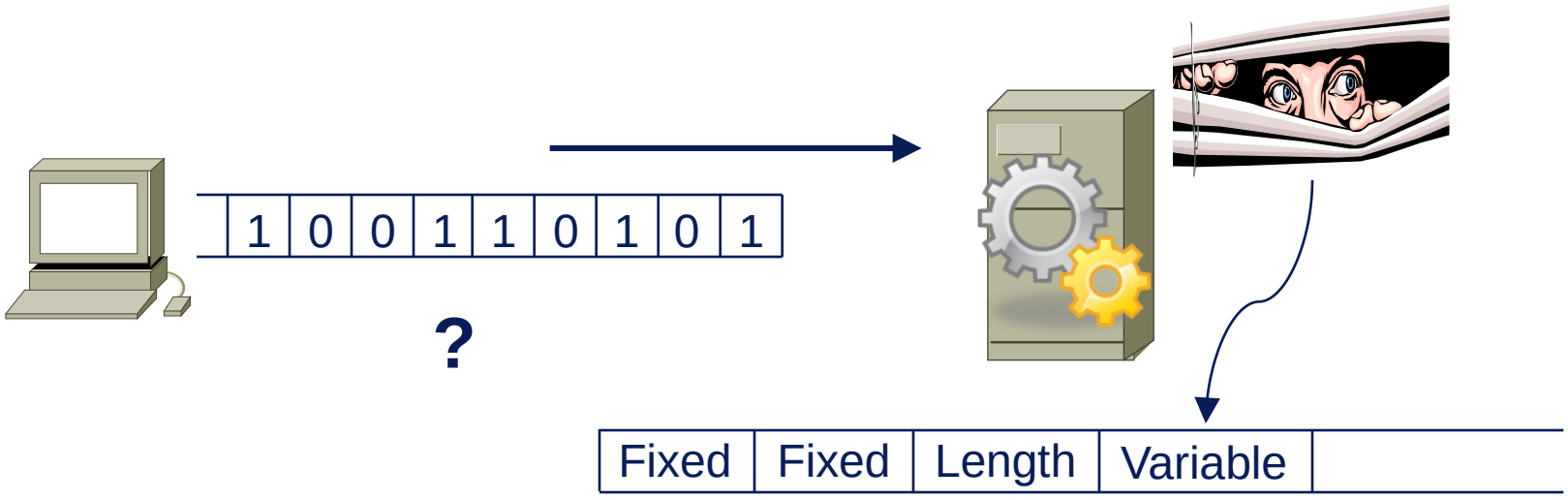
We propose techniques to address these challenges

Related work

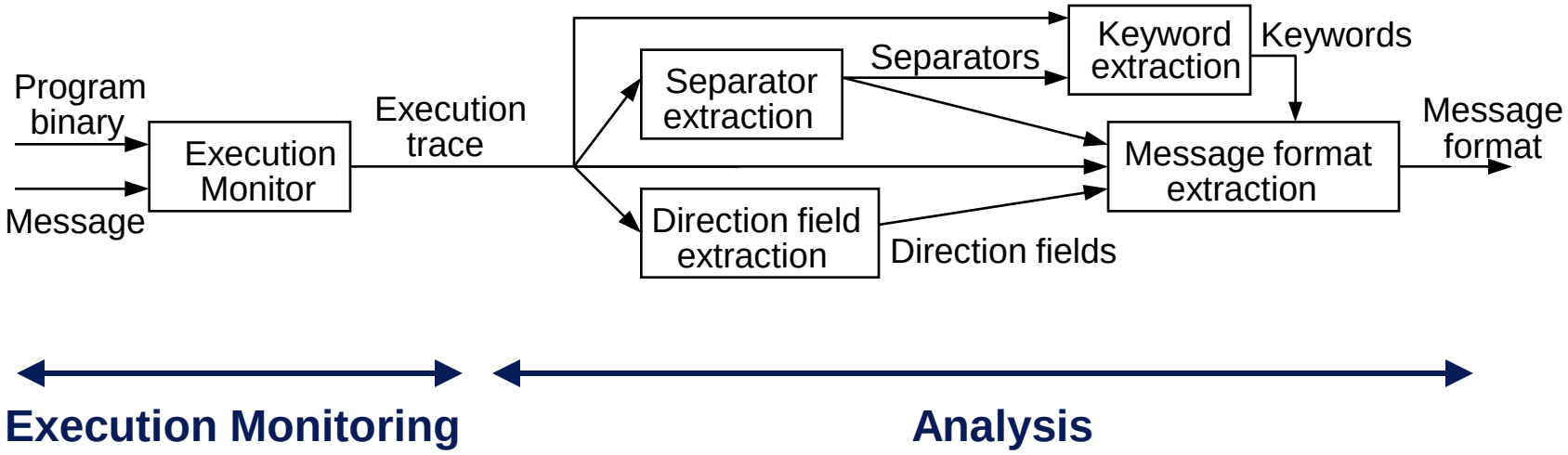
- **Previous work focuses on** network traces
- **Fundamental limitation:** lack of protocol semantics
- **Protocol Message Format: [Cui06,Cui07,Leita05,Leita06]**
  - **Need complex heuristics to identify direction fields**
  - **Need assumptions about separator values & data encoding**
  - **Cannot identify consecutive fixed-length fields**
- **Keywords / Application Signatures: [Haffner05,Ma06,Cui07]**
  - **Need tokens to appear at same position across messages**
  - **Problems: variable-length fields, floating fields**
- **Some previous work using binary analysis: [Lim06]**
  - **Assumes knowledge of program's output functions**

Approach

- **Shadowing: Monitor how a** binary **implementing the protocol** processes a received message
  - **How the message is parsed**
  - **How the message is used**



Polyglot: system architecture



- **Input: program binary and received message**
- **Output: message format**
- **Two phases:**
  - **Execution Monitoring → generate execution trace**
  - **Analysis → extract the message format**

Execution monitoring phase

- **Run the binary inside an emulator**
- **Implements dynamic taint analysis [Chow04,Suh04,Costa05, Newsome05, Crandall06]**
  - **Received network data marked as interesting**
  - **Marking propagates as data is used**
  - **Marking represents offsets in input stream**
- **Outputs an execution trace which contains**
  - **Executed instructions**
  - **Operand content during execution**
  - **Taint information**

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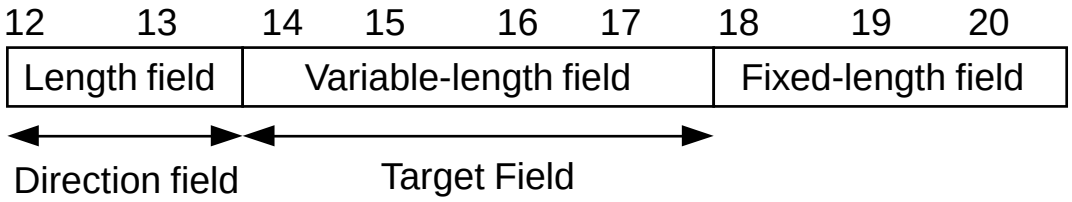
Direction fields

- **Direction Fields: store information about the location of another target field in the message**
- **Target field has variable-length**
- **Three types of direction fields**
  - **Length fields**
    - **Encode length of target field**
  - **Pointer fields**
    - **Encode displacement relative to another position**
  - **Counter fields**
    - **Encode position of field in a list of items**

Direction field extraction



- **Detect direction fields when used to increment the value of a pointer**
- **Two methods to increment the pointer:**
  - **Direct: increment computed from field and added to pointer**
    - » **Indirect memory access that 1) accesses a tainted memory position, and 2) where the destination address has been computed from tainted data**
  - **Indirect: increment computed using a loop**
    - » **Need to find loops and check if they have tainted conditions**

Direction field extraction

- **No assumptions about field encoding used**
  - » **number of bytes/words/quadwords,**
  - » **integer / string**
- **Variable-length fields:**
  - – **Direction fields need to appear before variable-length fields**
  - – **Variable-length field: the sequence of bytes between the last position belonging to the direction field and the end of the target field**

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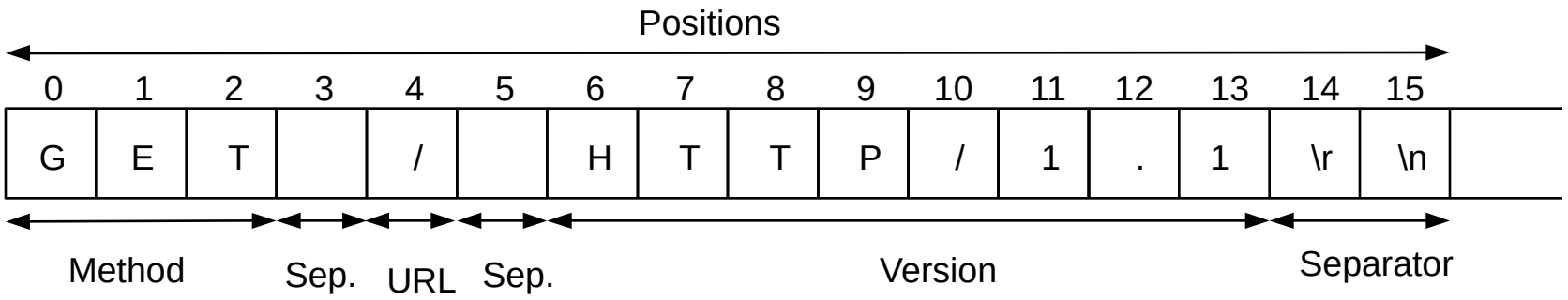
Separators

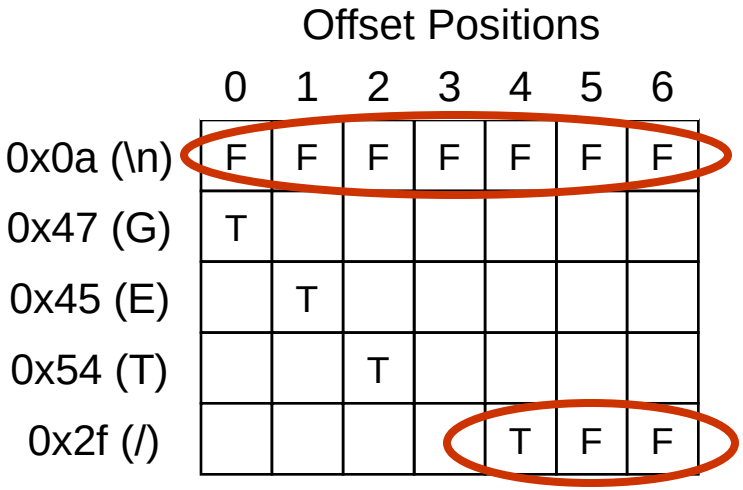


- **Used by protocols to mark the boundary of variable-length fields**
- **Separator = Constant + Scope**
  - **Constant marks the boundary**
  - **Scope contains list of positions in the message where the separator is used**
- **Two separator types depending on scope: Field, In-fields**

Separator extraction

- **Program compares the separator value against all positions in the separator scope until it finds it**
- **Intuition: find tokens that are compared against consecutive positions in the received data**
- **Three step process:**
  1. **Summarize tainted comparisons (comparison table)**
  2. **Extract byte-long separators**
  3. **Extend byte-long separators into multi-byte separators**

Tokens



Comparison table

No assumptions about separator value or encoding

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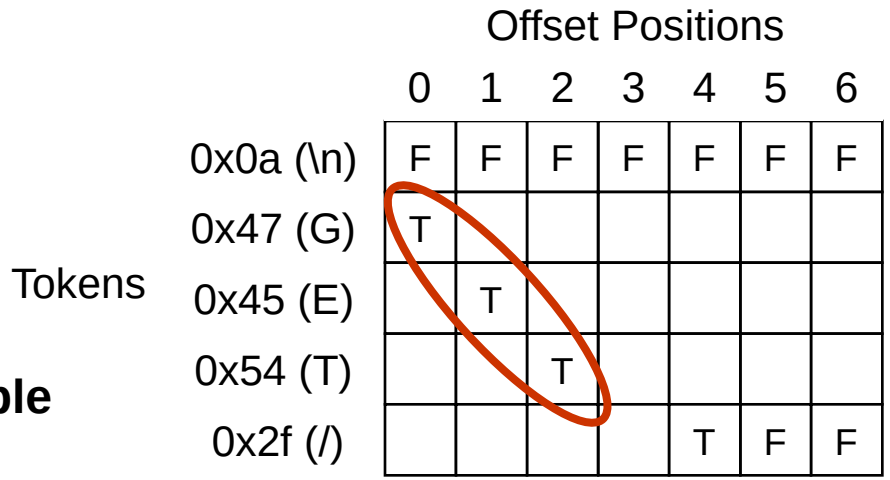
Keywords

- **Protocol constants that:**
  - **appear in the received application data**
  - **are supported by the implementation**
- **Keywords can be strings or numbers**
  - **“Content-type” in HTTP**
  - **Version number**
- **Useful to match traffic to protocols**

Keyword extraction

- **Program compares the supported keywords against the received data**
- **Intuition: analyze** true comparisons **that include tainted data**
- **Two phases**
  - **Populate the comparison table**
  - **Extract true comparisons at consecutive positions**
    - » **Break keywords at false comparisons or separators**



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Multi-byte fixed length fields

- **Intuition: program operates on the entire field**
  - **All field bytes need to be considered for comparisons, arithmetic operations…**
- **Most fields are independent**
  - **Exceptions: direction fields, checksums**
- **Detection: for each instruction extract the list of positions it operates on**
  - **If not direction field, then create a new multi-byte fixed field**
- **Limitation: can only extract fields up to the system's word size → 4 bytes in 32-bit architectures**
  - **But, still better than previous work that separates each byte**

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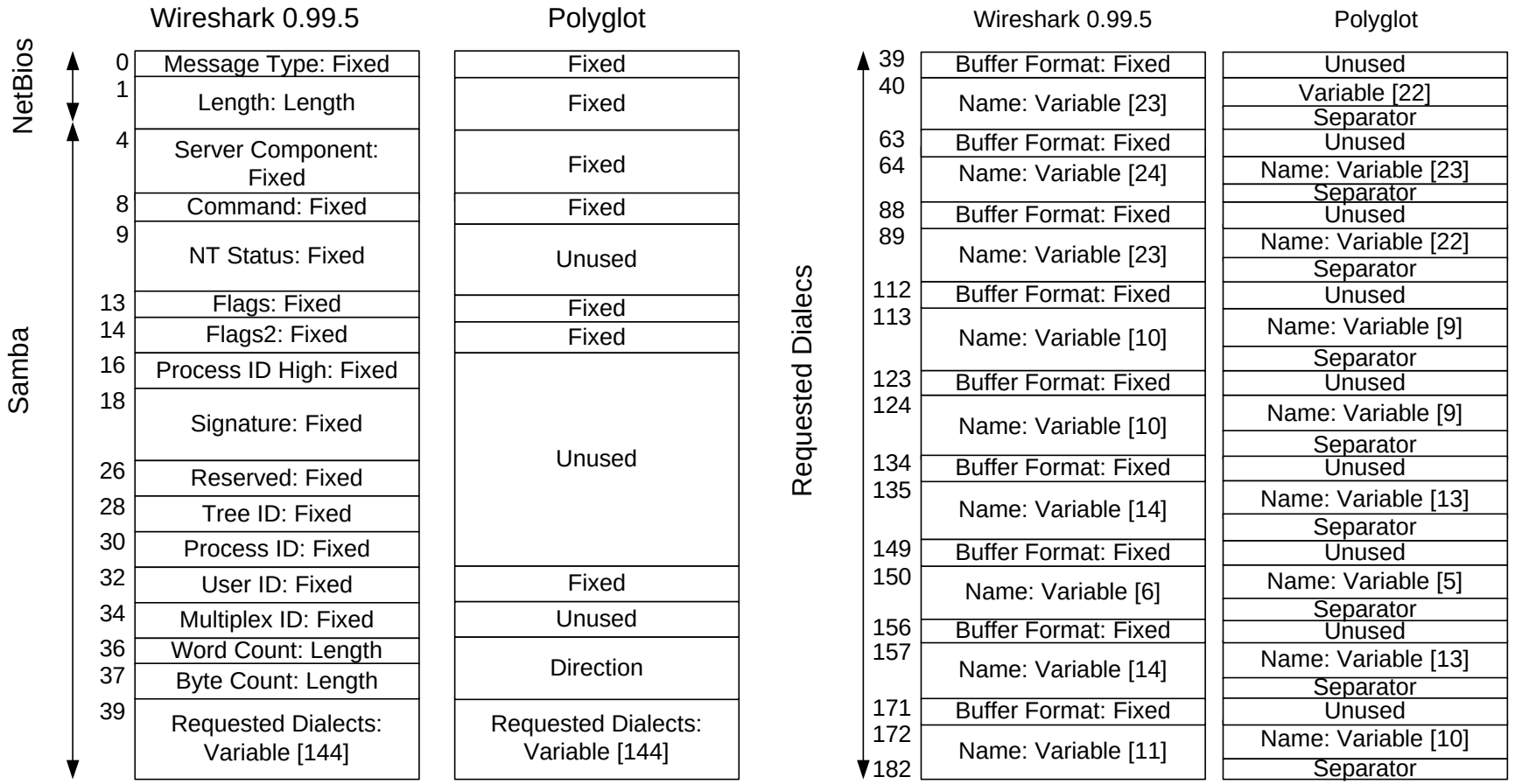
Evaluation overview

- **Evaluated on 11 programs and 5 protocols: HTTP, DNS, IRC, ICQ, Samba**
  - **Clients & Servers**
  - **Windows & Linux**
  - **Text & Binary**
- **Results compared to Wireshark**

Program	Version	Type	Size	OS
Apache	**2.2.4**	**HTTP server**	**4,344kB**	**Win.**
Miniweb	**0.8.1**	**HTTP server**	**528kB**	**Win.**
Savant	**3.1**	**HTTP server**	**280kB**	**Win.**
Bind	**9.3.4**	**DNS server**	**224kB**	**Win.**
MaraDNS	**1.2.12.4**	**DNS server**	**164kB**	**Win.**
SimpleDNS	**4.00.06**	**DNS server**	**432kB**	**Win.**
TinyICQ	**1.2**	**ICQ client**	**11kB**	**Win.**
Beware ircd	**1.5.7**	**IRC server**	**148kB**	**Win.**
JoinMe	**1.41**	**IRC server**	**365kB**	**Win.**
Unreal IRCd	**3.2.6**	**IRC server**	**760kB**	**Win.**
Sambad	**3.0.24**	**Samba server**	**3,580kB**	**Linux**

- **Only Samba, HTTP results presented for brevity**

Samba results



- **Negotiate Protocol request**

HTTP separators

Separator	Apache	Savant	Miniweb
0x0d0a (‘\r\n’)	**Field**	**Field**	**Field**
0x2f (‘/’)	**In-field**	**In-field**	**-**
0x2e (‘.’)	**In-field**	**In-field**	**In-field**
0x20 (‘ ‘)	**-**	**In-field**	**In-field**
0x3a20 (‘: ‘)	**In-field**	**-**	**-**

GET /index.html HTTP/1.1
Host: 10.0.0.1
User-Agent: Mozilla/5.0 (X11; U; Linux i686; en-US; rv:1.8.1.1) Gecko/20061208 Firefox/2.0.0.1
Accept: text/xml,application/xml,application/xhtml+xml,text/html;q=0.9,text/plain;q=0.8,image/png,*/*;q=0.5
Accept-Language: en-us,en;q=0.5
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Keep-Alive: 300
Connection: Keep-Alive

HTTP keywords

Keyword	Apache	Savant	Miniweb
GET	**Yes**	**Yes**	**Yes**
Host	**Yes**	**NS**	**Yes**
User-Agent	**NS**	**Yes**	**NS**
Accept	**Yes**	**Yes**	**NS**
Accept-Language	**Accept**	**Yes**	**NS**
Accept-Encoding	**Accept-**	**Accept-**	**NS**
Accept-Charset	**Accept-**	**Accept-**	**NS**
Keep-Alive	**NS**	**NS**	**NS**
Connection	**Yes**	**Yes**	**Yes**

Server	Add. keywords
Apache	**'HTTP/', 'e', 'Keep-Alive'**
Savant	**'HTTP/1.', 'Keep-Alive', ':'**
Miniweb	**-**

GET /index.html HTTP/1.1
Host: 10.0.0.1
User-Agent: Mozilla/5.0 […]
Accept: text/xml,application/xml,application/xhtml+xml,text/html;q=0.9,text/plain;q=0.8,image/png,*/*;q=0.5
Accept-Language: en-us,en;q=0.5
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Keep-Alive: 300
Connection: Keep-Alive

Conclusion

- **Proposed a new approach for extracting the protocol** message format **using dynamic binary analysis**
- **Proposed new techniques for:**
  1. **detecting** direction fields
  2. **detecting** separators
  3. **detecting** multi-byte fixed-length **fields**
  4. **extracting protocol** keywords
- **Evaluated techniques on 5 protocols and 11 programs. Results compared to Wireshark**

Questions?