# Reverse Engineering Binary Messages through Design Patterns

**LangSec 2020**

**Jared Chandler**
Tufts University

Kathleen Fisher
Tufts University

# Automatic Reverse Engineering of Binary Messages

**Who does this:**

- Researchers
- Security Analysts
- Reverse Engineers

**Why:**

- Malware Communication Analysis
- Protocol Validation
- Old Gear with Lost Specification

**Related Problems:** Tags, Delimited Data, Long Distance Dependencies

**Our Focus:** Binary messages with *variable length*

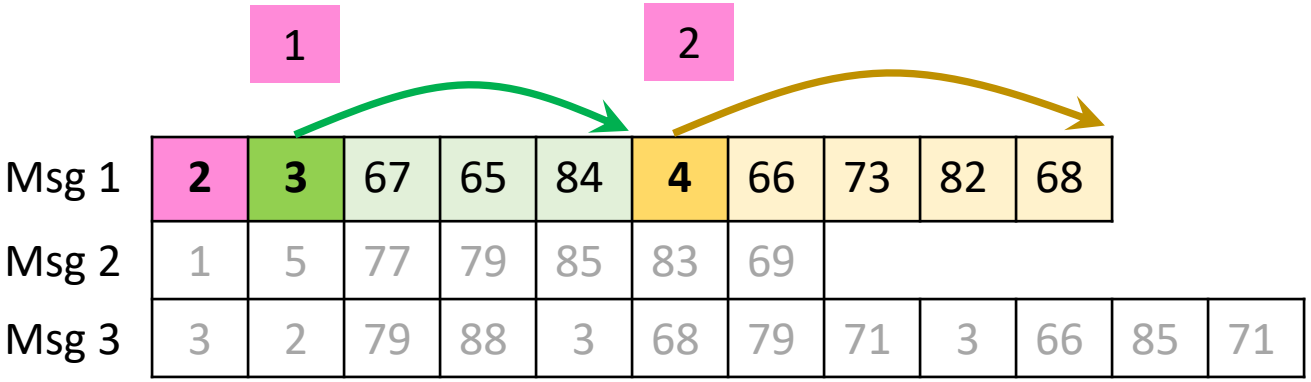
# Example of reverse engineering problem

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Msg 1 | 2 | 3 | 67 | 65 | 84 | 4 | 66 | 73 | 82 | 68 | | |
| Msg 2 | 1 | 5 | 77 | 79 | 85 | 83 | 69 | | | | | |
| Msg 3 | 3 | 2 | 79 | 88 | 3 | 68 | 79 | 71 | 3 | 66 | 85 | 71 |

1. The analyst starts with messages.

# Example of reverse engineering problem

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Msg 1 | 2 | 3 | 67 | 65 | 84 | 4 | 66 | 73 | 82 | 68 | |
| Msg 2 | 1 | 5 | 77 | 79 | 85 | 83 | 69 | | | | |
| Msg 3 | 3 | 2 | 79 | 88 | 3 | 68 | 79 | 71 | 3 | 66 | 85 | 71 |

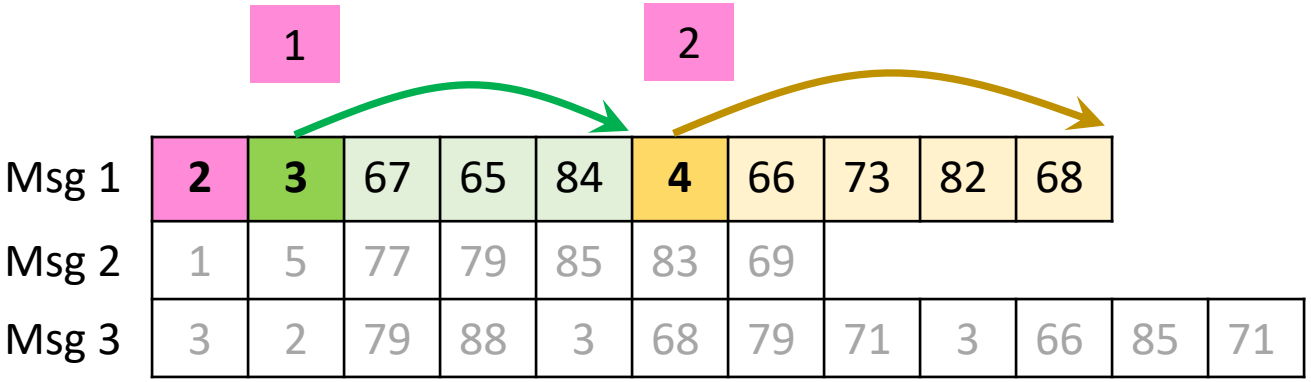


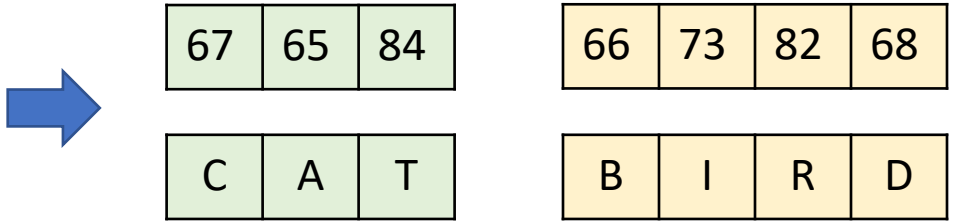

1. The analyst starts with messages.
2. Infers some pattern in the data.

# Example of reverse engineering problem

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Msg 1 | 2 | 3 | 67 | 65 | 84 | 4 | 66 | 73 | 82 | 68 | |
| Msg 2 | 1 | 5 | 77 | 79 | 85 | 83 | 69 | | | | |
| Msg 3 | 3 | 2 | 79 | 88 | 3 | 68 | 79 | 71 | 3 | 66 | 85 | 71 |

1. The analyst starts with messages.
2. Infers some pattern in the data.
3. Develops a hypothesis.

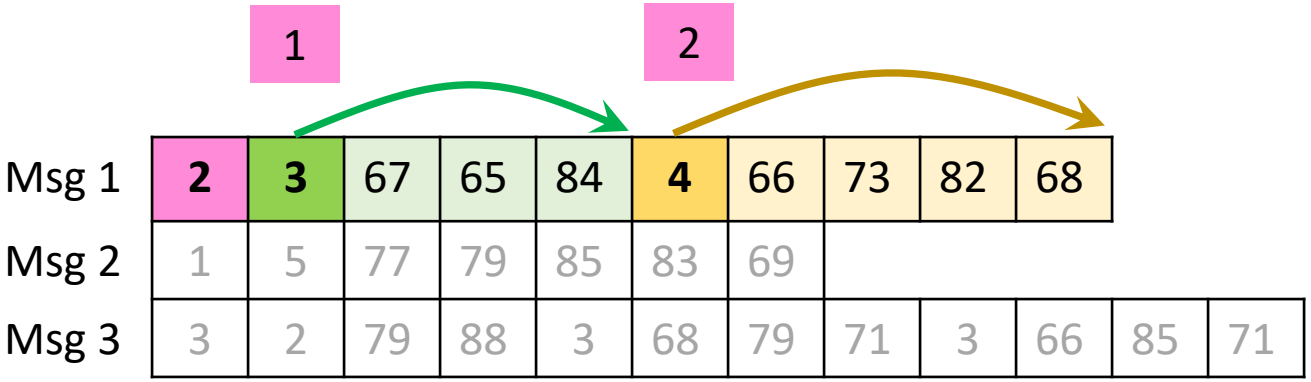


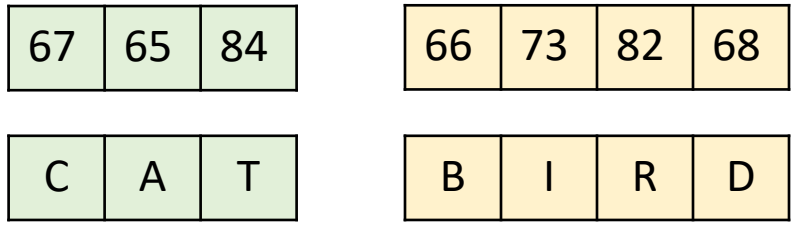



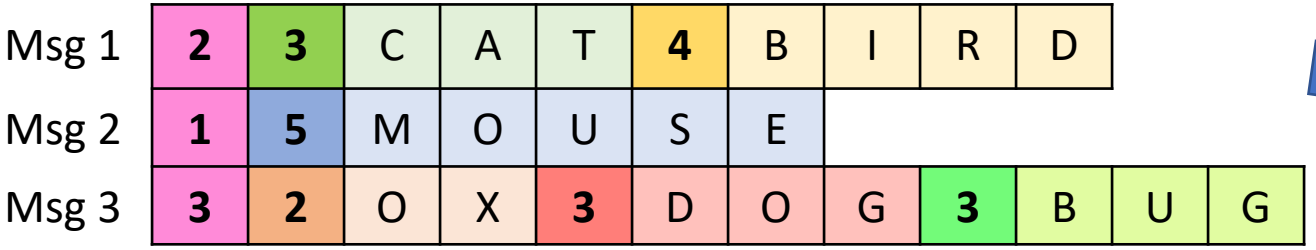
# Example of reverse engineering problem

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Msg 1 | 2 | 3 | 67 | 65 | 84 | 4 | 66 | 73 | 82 | 68 | |
| Msg 2 | 1 | 5 | 77 | 79 | 85 | 83 | 69 | | | | |
| Msg 3 | 3 | 2 | 79 | 88 | 3 | 68 | 79 | 71 | 3 | 66 | 85 | 71 |

1. The analyst starts with messages.
2. Infers some pattern in the data.
3. Develops a hypothesis.
4. Validates it on all messages.

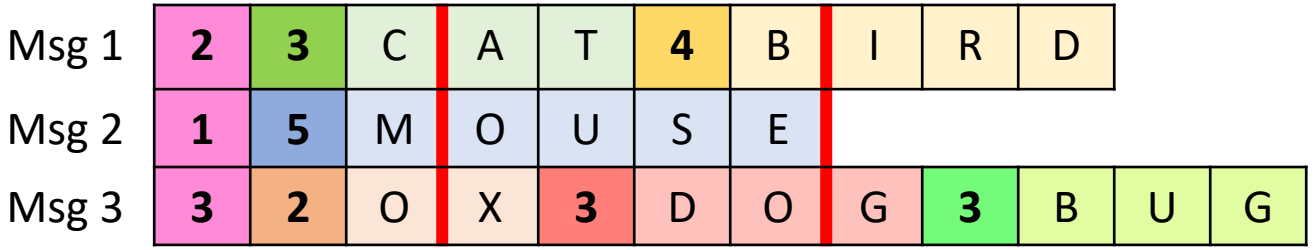


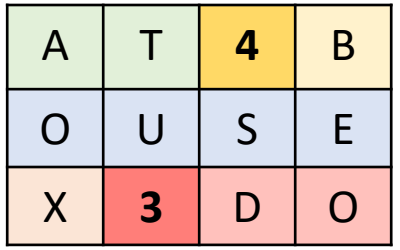



# What makes this problem hard for a human?

- Can take a long time to find a pattern in the data.
- Bytes at the same offset don't always come from the same **field** or **type**



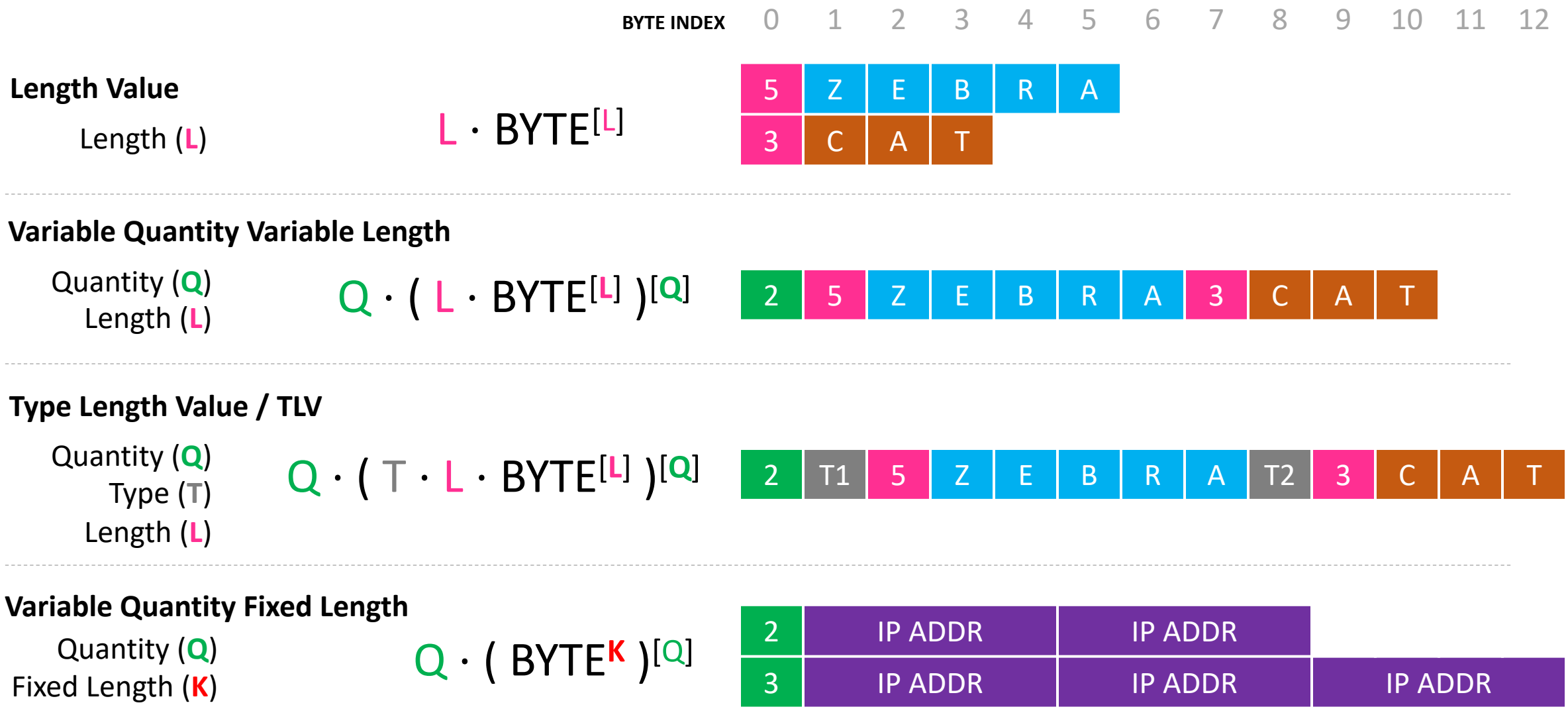

- Messages can be hundreds or thousands of bytes in size.

311 Byte Msg

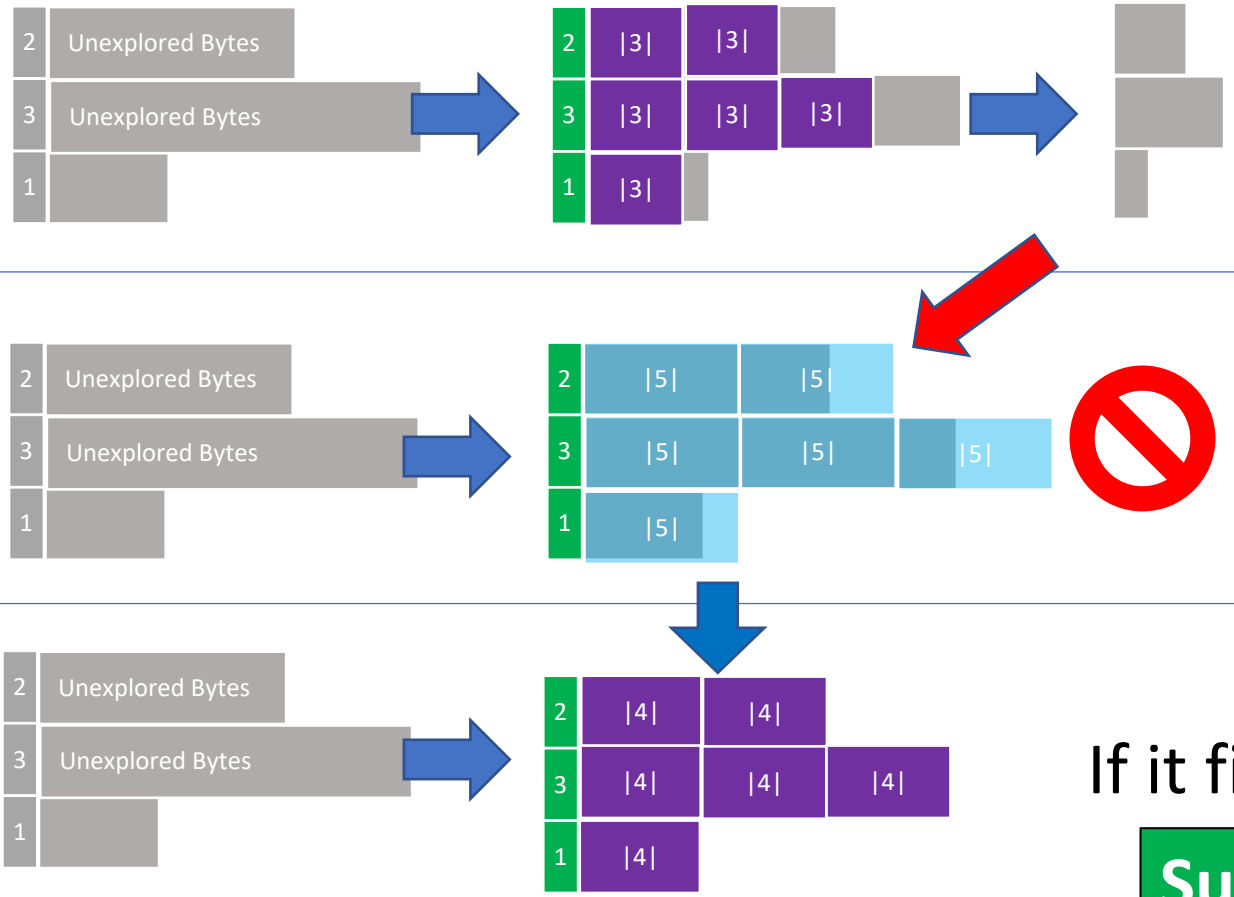

40D513C4221EF3E2EEB96F37D3EB1C10805124771BCB9C146746E2A26CC30EB9E97BBB44821416CEF424837EEBBE8138D2B222B7D
B07DE3FBFD791AABB867E876E2D699A0CC2A58299AB227A5822EC480A8C5F9FD7678036093DDA2575C3A762A4EA2F17D18BCC15
385D7973B03128EFCB15CB317A5226B1B6654B01B116A56738B4B5B779F8D68334328C018C64C07A930DCD548F7C6B7A1952E26F2
CA05340EC63BFEF513F3C1E8EB6AF00E14DC5000FE0A9CE5F876B56D7DA73352527329B60B66C552D469F3A2B12A4573B2C111557
4FC4D30F8372A52D868DCC38D7739E94D2C0815000D3B692DCA6D82693AD93D102222D349E9EC4D101F67FC9E702B5430AFB73AB
5361120902A82E4A6FDFF252809B36106B3C3FEC2FC8A98AFC642F1926BD4B3E72C39272004F2B8F731F8145A43D7B4D78BC

# Our Automated Approach

# Common Serialization Design Patterns



# Approach for fitting design patterns to data




Apply a single design pattern to all messages.
Recurse on leftovers.

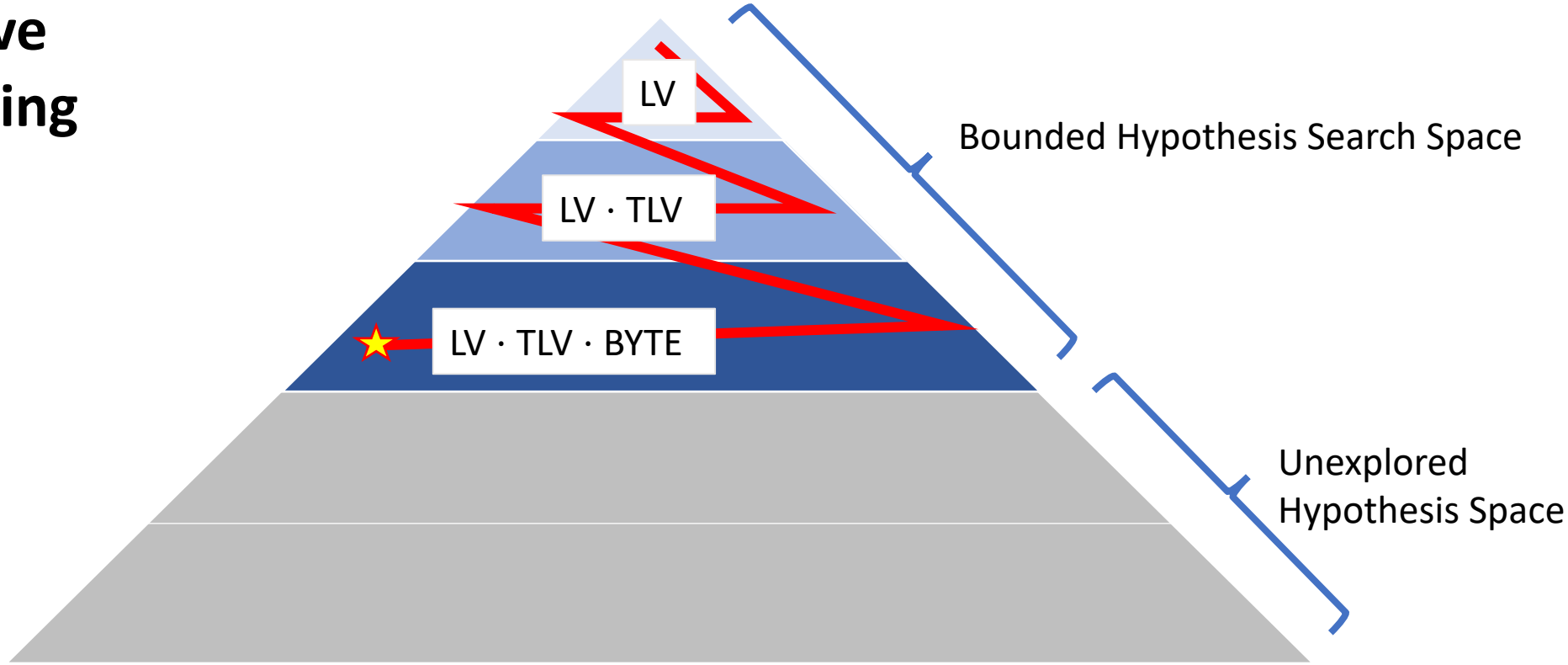
If we index off the end of any message, try a different pattern.

If it fits…

**Success!**

# Hypothesis Space Exploration

**Iterative Deepening**



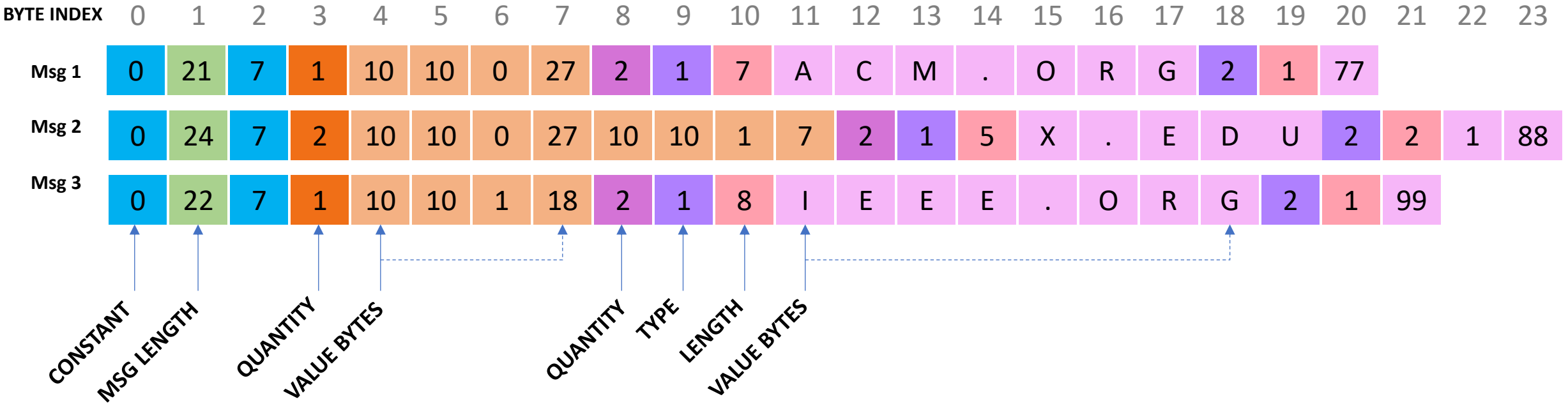

★ = Hypothesis consistent with message samples

# How does our approach perform?

| Experimental Condition | Test Cases | Accuracy |
|---|---|---|
| Patterns with random values | 16500 | 99.9% |
| Patterns with values from real network traffic | 1434 | 99.37% |

1. Generated permutations of Design Patterns (*Example:* $LV \cdot VQVL \cdot VQFW_4$ )
2. Used each permutation to serialize values creating 100 messages.
3. Ran our inference Algorithm on each collection of 100 messages.
4. Compared Inferred Patterns with those used to Serialize.

# Further Evaluation: Botnet CnC Attack Commands




**Inferred Format 1: BYTE, BYTE, BYTE, VQFL, TLV**

**Inferred Format 2: BYTE, BYTE, BYTE, VQFL, BYTE, BYTE, LV, BYTE, LV**

# Next Steps

- Expand our tool box of design patterns through protocol taxonomy
- Parallelization
- Guided Search Heuristics

# Thank You

Jared Chandler

jared.chandler@tufts.edu

**Acknowledgements:**

This material is based upon work partly supported by the Defense Advanced Research Projects Agency (DARPA) under Contract No.HR0011-19-C-0073.

This project was sponsored in part by the Air Force Research Laboratory (AFRL) under contract number FA8750-19-C-0039. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the United States Air Force.