SQL Injection Isn't Dead

Smuggling Queries at the Protocol Level

Paul Gerste – Hack.lu 2024 – October 24, 2024

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SQL INJECTION LOWER DECKS

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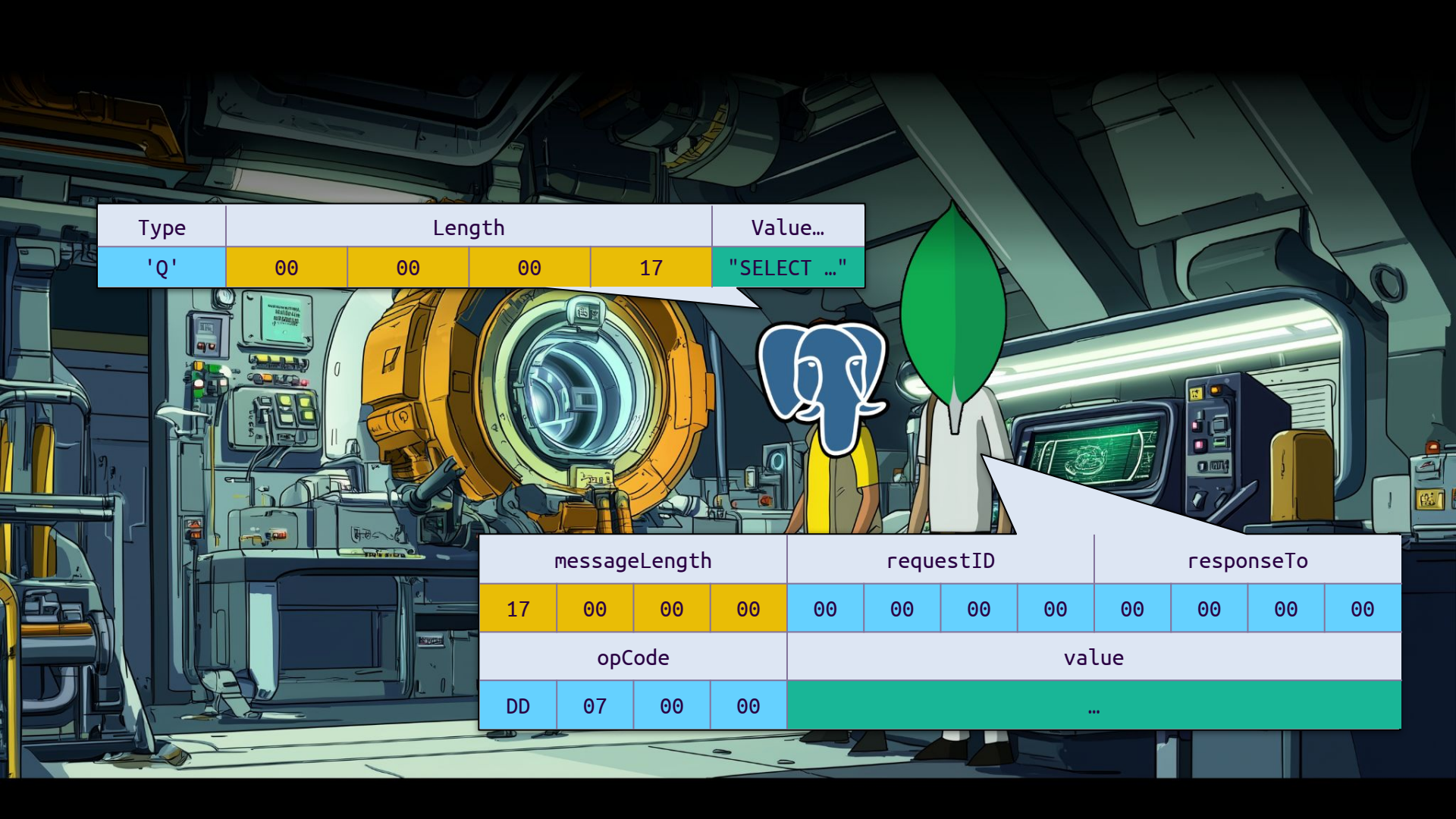
HGETALL user:1
SELECT * FROM users WHERE id=1
db.users.find({
id: 1,
})
MySQL


Type
Length
Value…
'Q'
00
00
00
17
"SELECT …"
messageLength
requestID
responseTo
17
00
00
00
00
00
00
00
00
00
00
00
opCode
value
DD
07
00
00
…

Teaser

```
func getUser(w http.ResponseWriter, req *http.Request) (user User) {
    body, _ := io.ReadAll(req.Body)
    id := string(body)
    db.QueryRow("SELECT * FROM users WHERE id=$1", id).Scan(&user)
    // ...
}
```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SELECT * FROM speakers

- Paul Gerste
  - Vulnerability Researcher at Sonar
- I love to break (web) stuff
- I love to play and organize CTFs with FluxFingers
  - Hack.lu CTF challenges are still up!

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Outline

- The Idea
- Attacking Database Wire Protocols
  - PostgreSQL
  - MongoDB
- Real-World Applicability
- Future Research
- Takeaways

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The Idea

Request smuggling, but for binary protocols

Request smuggling...

HTTP Desync Attacks: Request Smuggling Reborn

James Kettle
Director of Research
@albinowax

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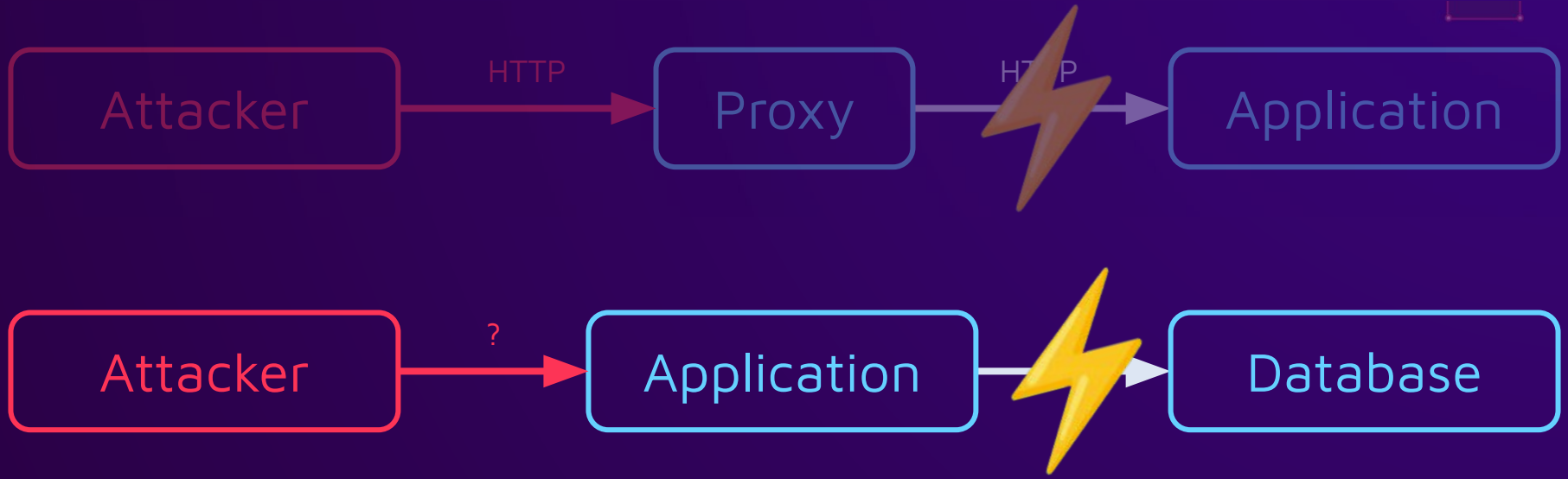
... but for binary protocols



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Why **Database** Wire Protocols?

- Applicability
  - Almost every web app has a database
- Severity
  - Interesting data (e.g., PII)
  - Relevant data (e.g., for authentication)
- Exploitability
  - Most queries contain some user input

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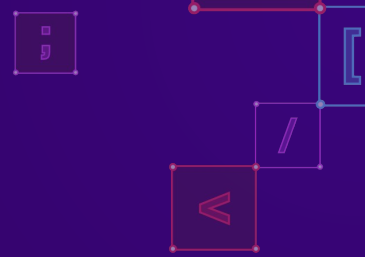
Attacking Database Wire Protocols



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High-Level Protocol Comparison

- PostgreSQL
- MySQL
- MongoDB

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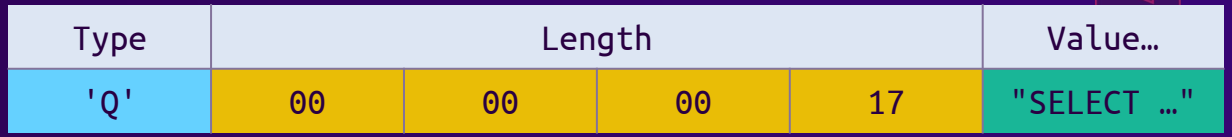
High-Level Protocol Comparison

- **PostgreSQL**
- MySQL
- MongoDB



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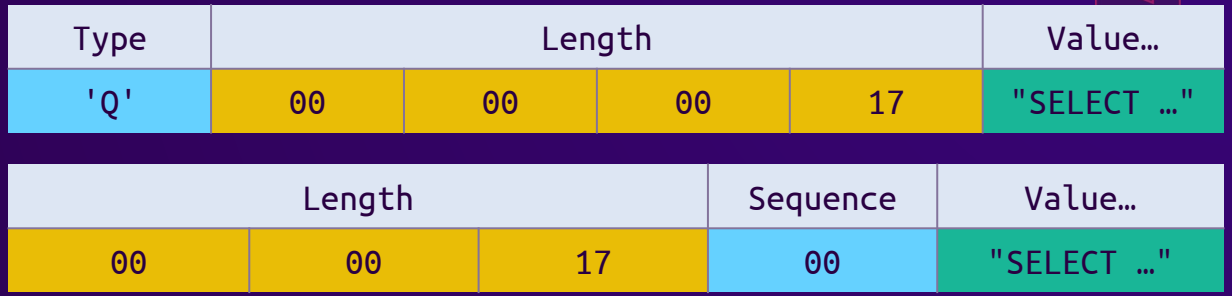
High-Level Protocol Comparison

- PostgreSQL
- **MySQL**
- MongoDB



Type	Length				Value…
'Q'	00	00	00	17	"SELECT …"

Length			Sequence	Value…
00	00	17	00	"SELECT …"

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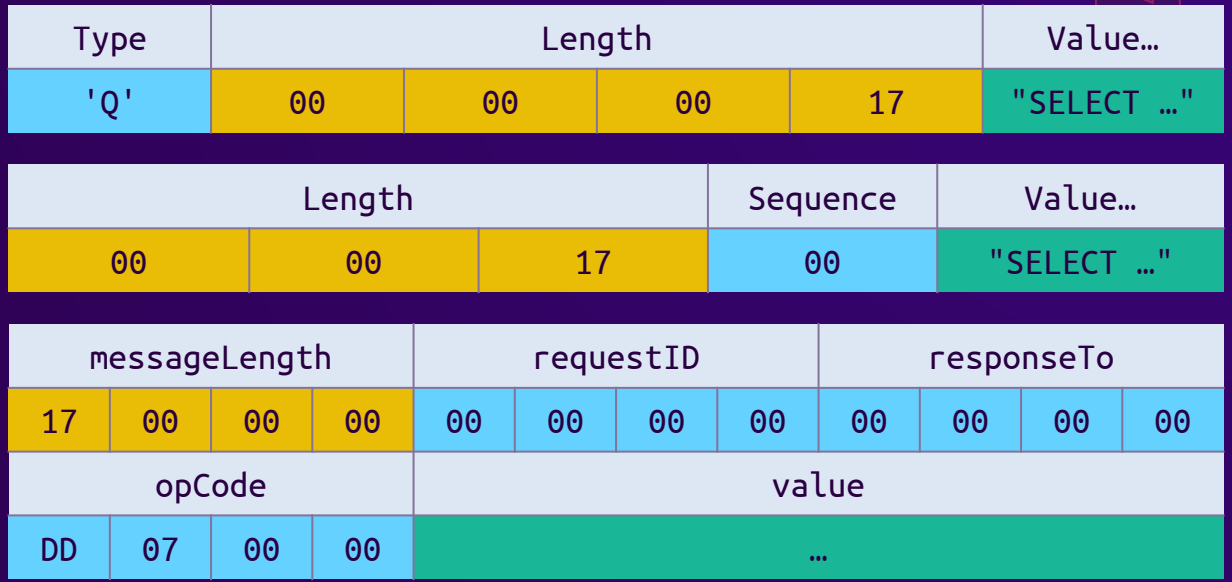
High-Level Protocol Comparison

- PostgreSQL
- MySQL
- **MongoDB**



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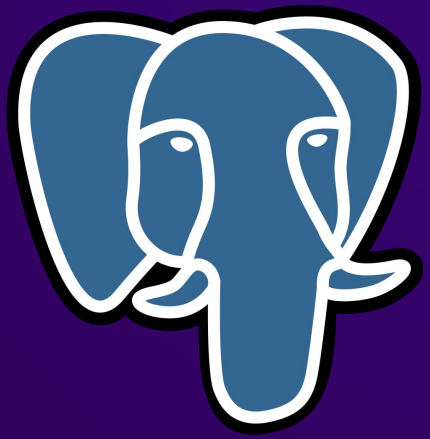
Case Study:

PostgreSQL



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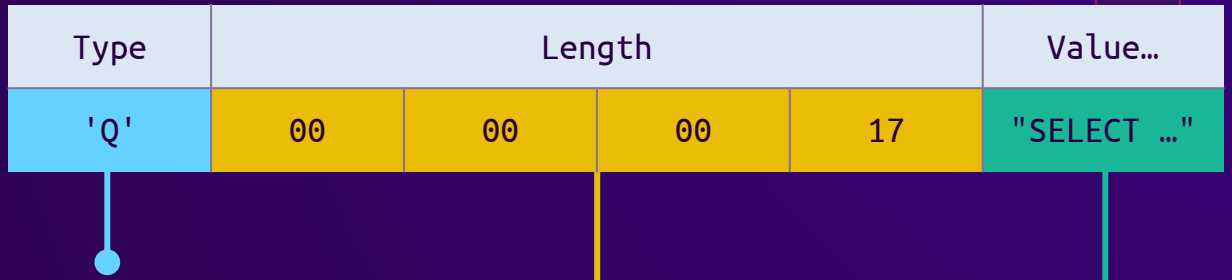
PostgreSQL Wire Protocol



- Type: 1-byte identifier
- Length: 4-byte integer
- Value

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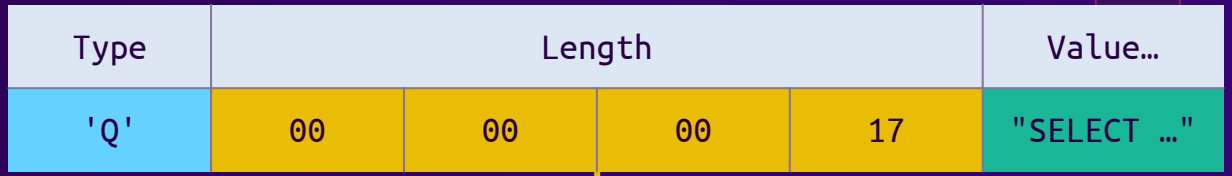
PostgreSQL Wire Protocol



- Type: 1-byte identifier
- Length: 4-byte integer
- Value

Max value: $2^{32}-1$

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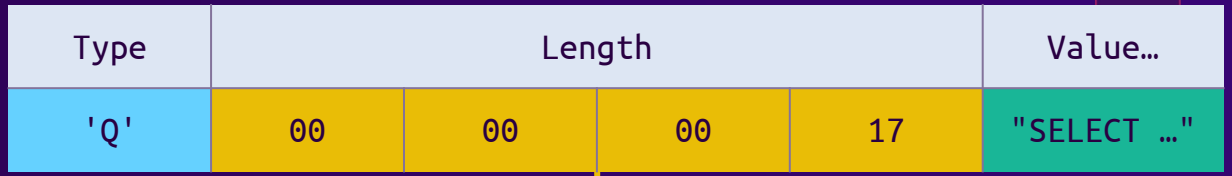
PostgreSQL Wire Protocol



- Type: 1-byte identifier
- Length: 4-byte integer
- Value

Max value: $2^{32}-1$

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The Bug: pgx

```
func (src *Bind) Encode(dst []byte) []byte {
    dst = append(dst, 'B')
    sp := len(dst)
    // …
    pgio.SetInt32(dst[sp:], int32(len(dst[sp:])))
    return dst
}
```


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The Bug: pgx

```
func (src *Bind) Encode(dst []byte) []byte {
    dst = append(dst, 'B')
    sp := len(dst)
    // …
    pgio.SetInt32(dst[sp:], int32(len(dst[sp:])))
    return dst
}
```

Write message type

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The Bug: pgx

```
func (src *Bind) Encode(dst []byte) []byte {
    dst = append(dst, 'B')
    sp := len(dst)
    // …
    pgio.SetInt32(dst[sp:], int32(len(dst[sp:])))
    return dst
}
```

Save size offset

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The Bug: pgx

```
func (src *Bind) Encode(dst []byte) []byte {
    dst = append(dst, 'B')
    sp := len(dst)
    // …
    pgio.SetInt32(dst[sp:], int32(len(dst[sp:])))
    return dst
}
```

Build the rest

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The Bug: pgx

```
func (src *Bind) Encode(dst []byte) []byte {
    dst = append(dst, 'B')
    sp := len(dst)
    // …
    pgio.SetInt32(dst[sp:], int32(len(dst[sp:])))
    return dst
}
```

Write size

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The Bug: pgx

```
func (src *Bind) Encode(dst []byte) []byte {
    dst = append(dst, 'B')
    sp := len(dst)
    // …
    pgio.SetInt32(dst[sp:], int32(len(dst[sp:])))
    return dst
}
```

The message buffer

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The Bug: pgx

```
func (src *Bind) Encode(dst []byte) []byte {
    dst = append(dst, 'B')
    sp := len(dst)
    // …
    pgio.SetInt32(dst[sp:], int32(len(dst[sp:])))
    return dst
}
```

Buffer length (int)

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The Bug: pgx

```
func (src *Bind) Encode(dst []byte) []byte {
    dst = append(dst, 'B')
    sp := len(dst)
    // …
    pgio.SetInt32(dst[sp:], int32(len(dst[sp:])))
    return dst
}
```

Truncate to `int32`

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Message Size Overflow

Size: 8 = 0x00000008

4 bytes length + 4 bytes data

Payload: "A" * 4

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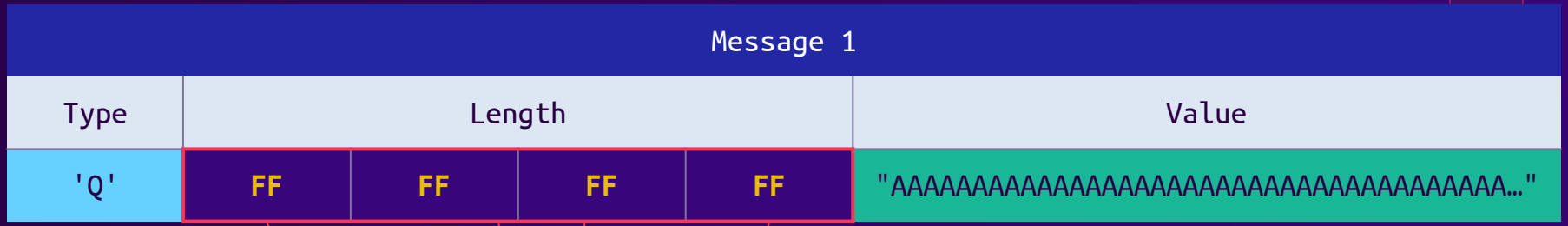
Message Size Overflow



Size: 2^{32}-1 = 0xFFFFFFFF

4 bytes length + 2^{32}-5 bytes data

Payload: `"A" * (2**32 - 5)`

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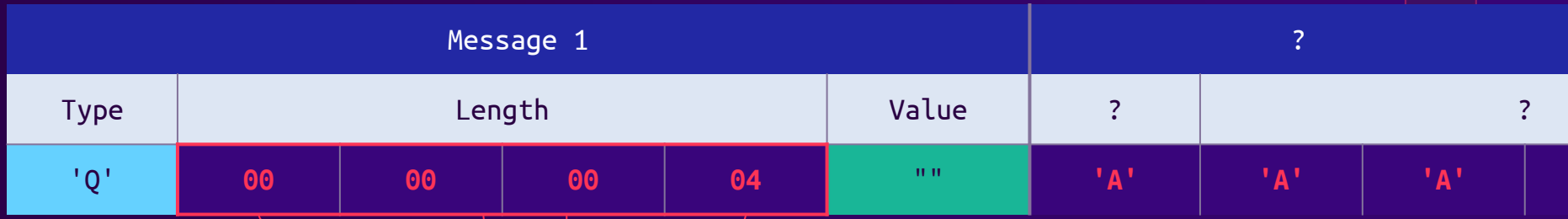
Message Size Overflow



Size: $2^{32}+4$ = 0x100000004

4 bytes length + 2^{32} bytes data

Payload: "A" * (2**32)

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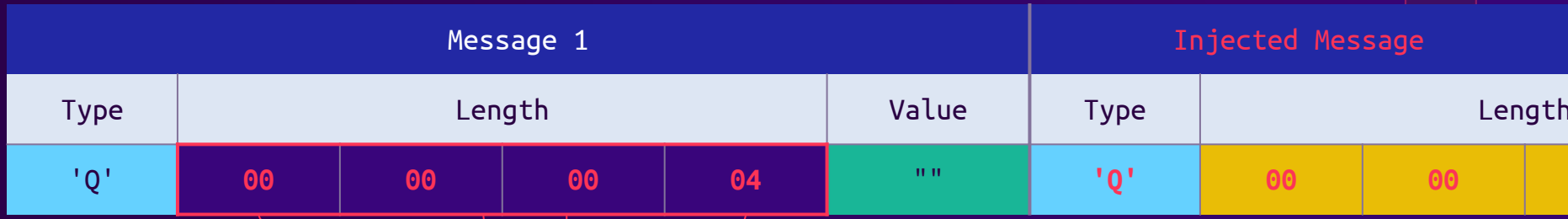
Message Size Overflow



Size: $2^{32}+4$ = 0x100000004

4 bytes length + 2^{32} bytes data

Payload: fakeMsg + "A" * (2**32 - len(fakeMsg))

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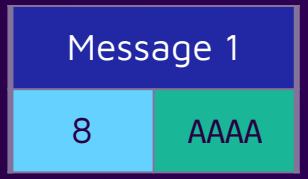
Message Size Overflow - Zoomed Out



Message Size Overflow - Zoomed Out

Message 1 ...

2^{32}-1 AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA...

... Message 1 ...

...AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA...

... Message 1 ...

...AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA...

... Message 1

...AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA

Message Size Overflow - Zoomed Out

Message 1 ...

$2^{32}+8$ AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA...

... Message 1 ...

Application

...AAAAA AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA...

... Message 1 ...

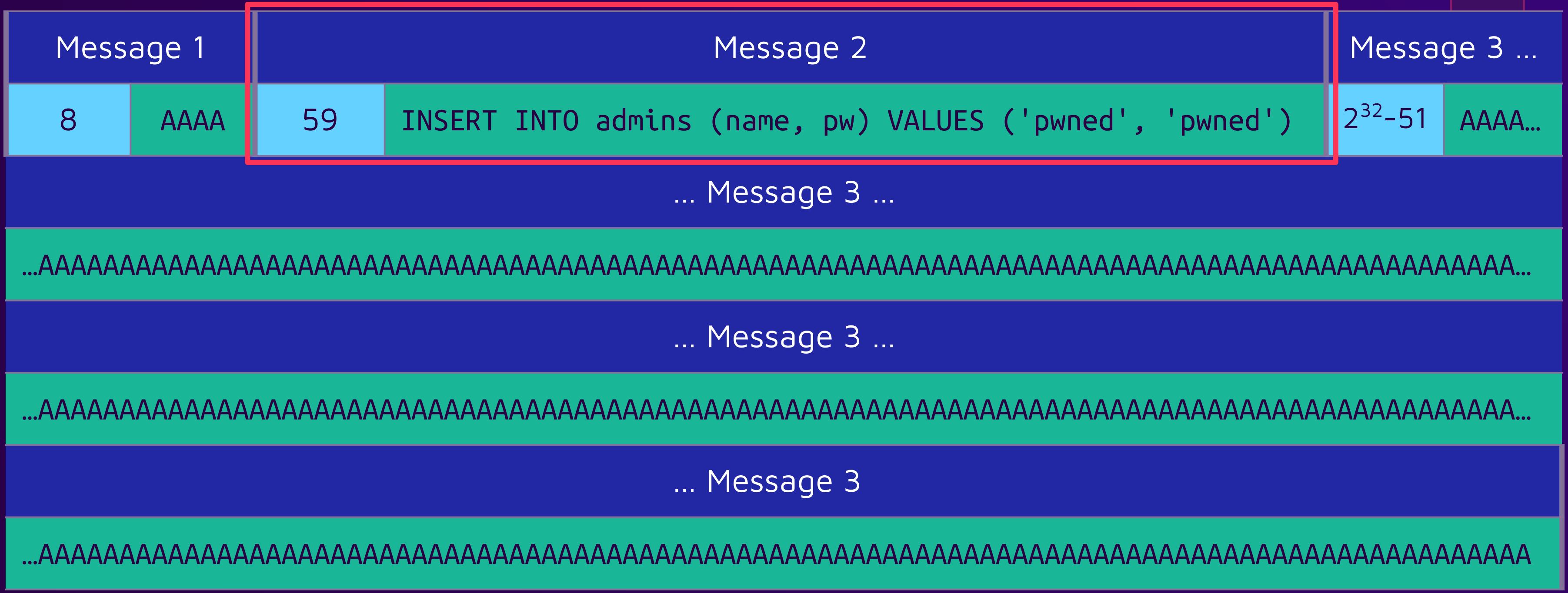
...AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA...

... Message 1

...AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA

Message Size Overflow - Zoomed Out

Message Size Overflow - Zoomed Out



Impact

- Inject entire SQL statements
  - Not limited to UNION, subqueries, etc.
  - Like stacked queries
- Read/write/delete all data in the DB
- Direct exfiltration is inconvenient
  - Application only processes the first DB response

How does it look in the real world?

How does it look in the real world?

```
id := "5831bfeb"

conn.QueryRow("SELECT * FROM users WHERE id = $1", id)
```

Type	Length				Value
'Q'	00	00	00	2e	SELECT * FROM users WHERE id = '5831bfeb'\x00

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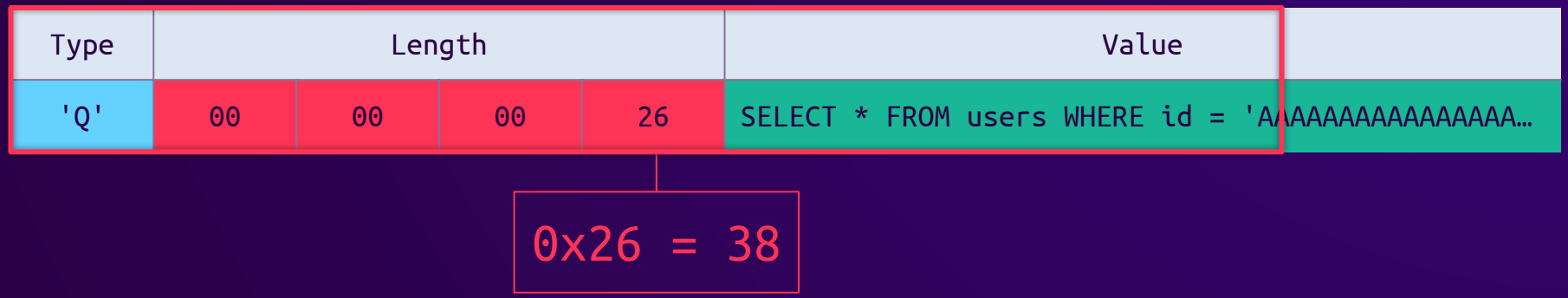
How does it look in the real world?

```
id := strings.Repeat("A", 1<<32)

conn.QueryRow("SELECT * FROM users WHERE id = $1", id)
```



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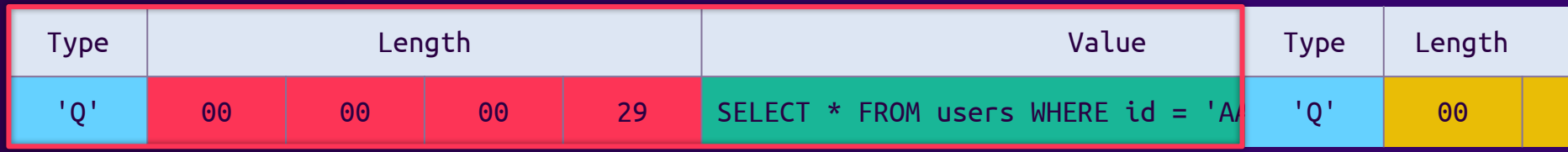
How does it look in the real world?

```
id := strings.Repeat("A", 1<<32)

conn.QueryRow("SELECT * FROM users WHERE id = $1", id)
```



How to know this offset?

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Crafting a Payload

- Offset depends on the query
  - Where is the injection point?
  - How long is the query?
- Calculate the offset when query is known
- What if it's not?

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Crafting a Payload: Magic Pattern

```
00000000:  5100 5100 5100 5100 5100 5100 5100 5100   Q.Q.Q.Q.Q.Q.Q.Q.
00000010:  5100 5100 5100 5100 5100 5100 5100 5100   Q.Q.Q.Q.Q.Q.Q.Q.
```

…

Crafting a Payload: Magic Pattern

```
00000000:  5100 5100 5100 5100 5100 5100 5100 5100   Q.Q.Q.Q.Q.Q.Q.Q.
00000010:  5100 5100 5100 5100 5100 5100 5100 5100   Q.Q.Q.Q.Q.Q.Q.Q.
```

…

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Crafting a Payload: Magic Pattern

	T	Length	Value	
00000000:	51	00 51 00	51 00 51 00 51 00 51 00	Q.Q.Q.Q.Q.Q.Q.Q.
00000010:	51	00 51 00	51 00 51 00 51 00 51 00	Q.Q.Q.Q.Q.Q.Q.Q.
…	Q	0x510051	…	
	✅	✅	✅	

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Crafting a Payload: Magic Pattern

```
00000000:  5100 5100 5100 5100 5100 5100 5100 5100  Q.Q.Q.Q.Q.Q.Q.Q.
00000010:  5100 5100 5100 5100 5100 5100 5100 5100  Q.Q.Q.Q.Q.Q.Q.Q.
```

…

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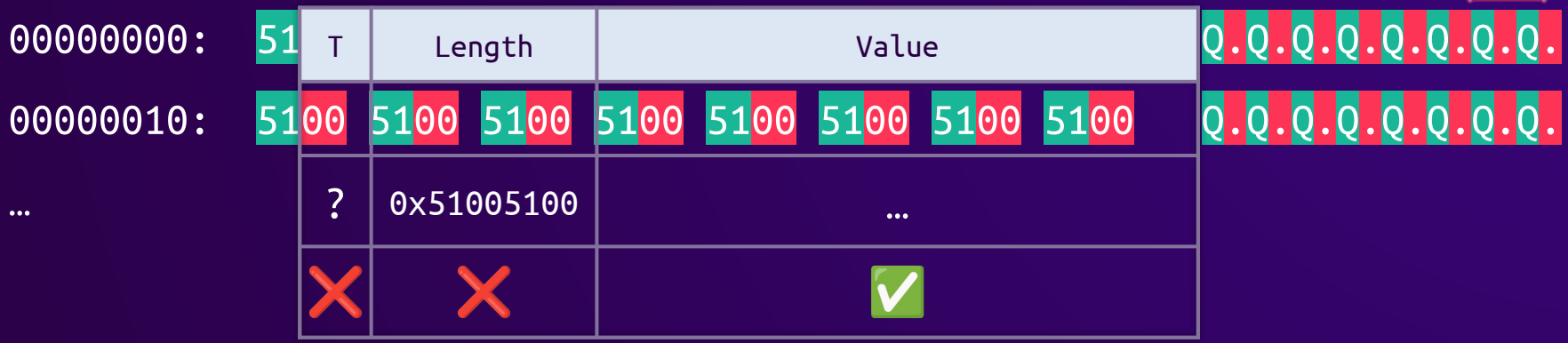
Crafting a Payload: Magic Pattern



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Crafting a Payload: Magic Pattern

```
00000000:  5100 5100 5100 5100 5100 5100 5100 5100   Q.Q.Q.Q.Q.Q.Q.Q.
00000010:  5100 5100 5100 5100 5100 5100 5100 5100   Q.Q.Q.Q.Q.Q.Q.Q.
```

…

- Success after ≤2 attempts!
  - 50% chance of success
  - Attack is repeatable, just change the offset

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Vulnerable Libraries

Language	Library	Vulnerable?	Exploitable?	Fixed Versions
Go	pgx	✅	✅	4.18.2, 5.5.4
	pg	✅	✅	none
	pgdriver	✅	✅	none
	pq	✅	✅	none
C#/.NET	Npgsql	✅	✅	4.0.14, 4.1.13, 5.0.18, 6.0.11, 7.0.7, 8.0.3
Java	pgjdbc	❌	❌	-
	pgjdbc-ng	✅	❌	-
	r2dbc-postgresql	✅	❌	-
JS/TS	pg	✅	❌	-
	pg-promise	❌	❌	-
	pogi	✅	❌	-
	postgres	✅	❌	-
	@vercel/postgres	✅	❌	-

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Exploitable Applications

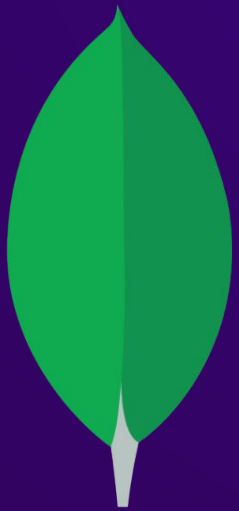
Demo: Harbor

- Container registry
  - CNCF Graduate project
  - Part of VMware Tanzu Kubernetes
- Default configuration was vulnerable
- No authentication required
- Fixed in 2.11.0 by updating pgx [1]

[1] https://github.com/goharbor/harbor/pull/20139

Case Study:

MongoDB



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MongoDB Wire Protocol

messageLength				requestID				responseTo			
17	00	00	00	00	00	00	00	00	00	00	00
opCode				value							
DD	07	00	00	…							

- 4-byte length field
- Queries are BSON documents
  - Hierarchical objects
  - Serialized to TLV sections

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The Bug: mongodb

```rust
async fn write_to<T: AsyncWrite + Send + Unpin>(&self, mut writer: T) -> Result<()> {
    let sections = self.get_sections_bytes();
    let total_length = Header::LENGTH
        + std::mem::size_of::<u32>()
        + sections.len()
        + /* ... */;
    let header = Header {
        length: total_length as i32,
        // ...
    };
    header.write_to(&mut writer).await?;
    writer.write_u32_le(self.flags.bits()).await?;
    writer.write_all(&sections).await?;
    // ...
}
```


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The Bug: mongodb

```rust
async fn write_to<T: AsyncWrite + Send + Unpin>(&self, mut writer: T) -> Result<()> {
    let sections = self.get_sections_bytes();
    let total_length = Header::LENGTH
        + std::mem::size_of::<u32>()
        + sections.len()
        + /* ... */;
    let header = Header {
        length: total_length as i32,
        // ...
    };
    header.write_to(&mut writer).await?;
    writer.write_u32_le(self.flags.bits()).await?;
    writer.write_all(&sections).await?;
    // ...
}
```

Get content bytes

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The Bug: mongodb

```rust
async fn write_to<T: AsyncWrite + Send + Unpin>(&self, mut writer: T) -> Result<()> {
    let sections = self.get_sections_bytes();
    let total_length = Header::LENGTH
        + std::mem::size_of::<u32>()
        + sections.len()
        + /* ... */;
    let header = Header {
        length: total_length as i32,
        // ...
    };
    header.write_to(&mut writer).await?;
    writer.write_u32_le(self.flags.bits()).await?;
    writer.write_all(&sections).await?;
    // ...
}
```

Calculate message size (usize)

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The Bug: mongodb

```rust
async fn write_to<T: AsyncWrite + Send + Unpin>(&self, mut writer: T) -> Result<()> {
    let sections = self.get_sections_bytes();
    let total_length = Header::LENGTH
        + std::mem::size_of::<u32>()
        + sections.len()
        + /* ... */;
    let header = Header {
        length: total_length as i32,
        // ...
    };
    header.write_to(&mut writer).await?;
    writer.write_u32_le(self.flags.bits()).await?;
    writer.write_all(&sections).await?;
    // ...
}
```

Truncate to i32

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Crafting a Payload

- Avoid bad bytes
  - Payload must be valid UTF-8
- Problem:
  - Message type (`dd 07`) is already invalid
  - Size fields can become invalid

Crafting a Payload

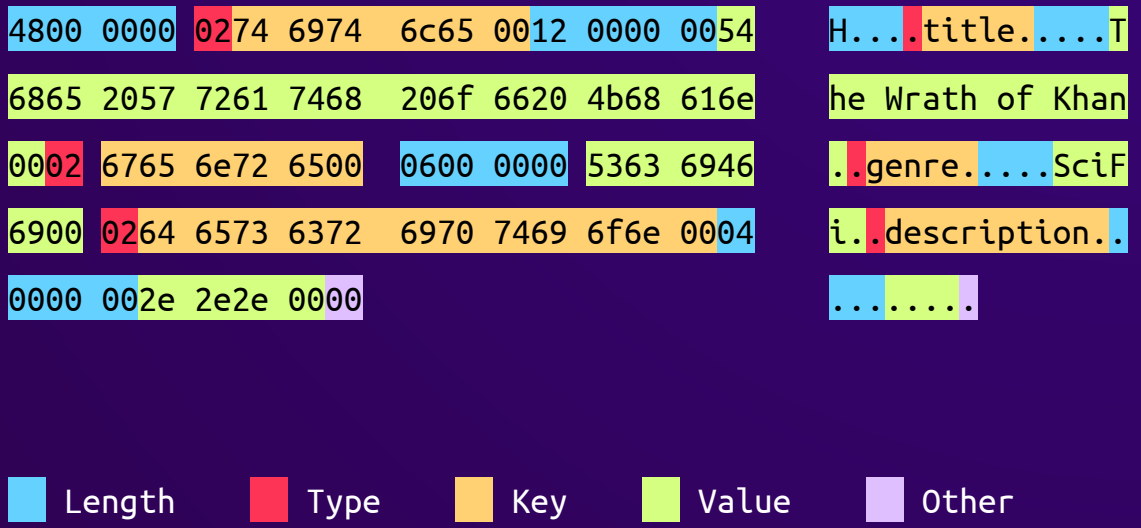
- Avoid bad bytes
  - Payload must be valid UTF-8
- Problem:
  - Message type (`dd 07`) is already invalid
  - Size fields can become invalid
- Solution:
  - Use metadata to create those bytes!

Crafting a Payload

Query:

```
{
  title: "The Wrath of Khan",
  genre: "SciFi",
  description: "...",
}
```

BSON Document:



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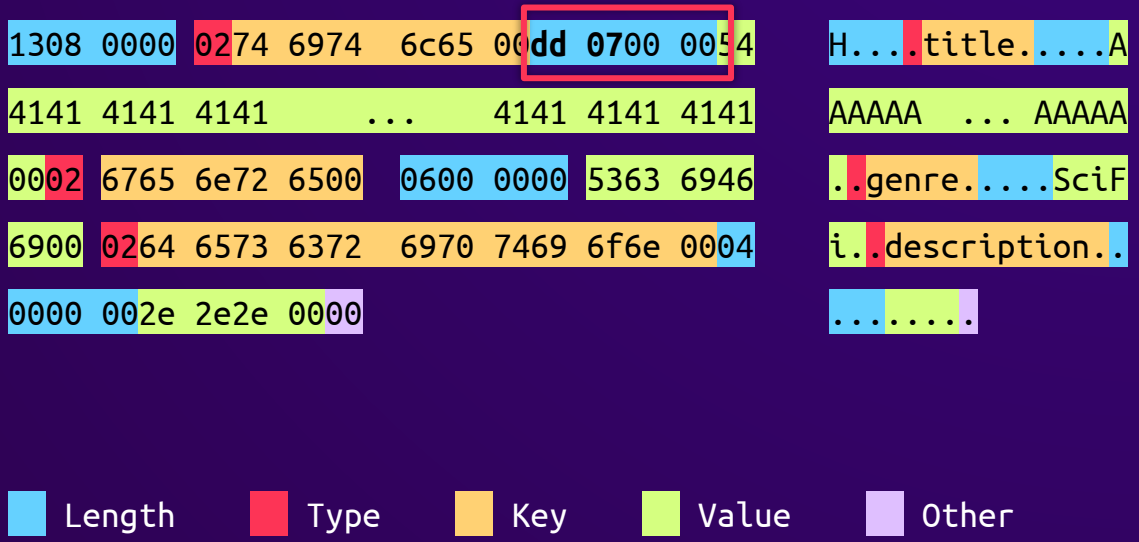
Crafting a Payload

Query:

```
{
  title: "A" * (0x7dd - 1),
  genre: "SciFi",
  description: "...",
}
```

BSON Document:



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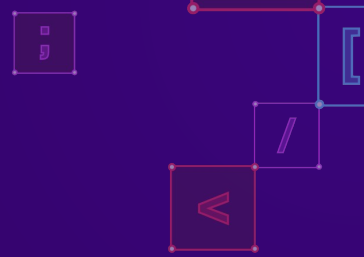
Vulnerable Libraries

Language	Library	Vulnerable?	Exploitable?	Fixed Version
Rust	`mongodb`	✅	✅	`2.8.2`
Python	`pymongo`	❌	❌	-
Go	`mongo`	❌	❌	-
Java	`mongo-java-driver`	❌	❌	-
JavaScript	`mongodb`	❌	❌	-

- Sent advisory in February 2024
- `mongodb` fixed in March

Real-World Applicability



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Constraints

How Web Apps Handle Large Payloads

- Aren't apps limiting input sizes?
- Common protections:
  - Size-limiting reverse proxies
  - Default body size limits
  - Maximum JSON/form decode sizes
  - ... and more

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How Web Apps Handle Large Payloads

- Potential bypasses
  - Unprotected endpoints
  - Compression
  - WebSockets
  - Server-side creation

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How Web Apps Handle Large Payloads

- Potential bypasses
  - **Unprotected endpoints**
  - Compression
  - WebSockets
  - Server-side creation

- No default limits
- Disabled limits
  - Harbor

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How Web Apps Handle Large Payloads

- Potential bypasses
  - Unprotected endpoints
  - **Compression**
  - WebSockets
  - Server-side creation

- Some enforce size limits

  before decompression
  - Nginx
  - Fastify

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How Web Apps Handle Large Payloads

- Potential bypasses
  - Unprotected endpoints
  - Compression
  - **WebSockets**
  - Server-side creation

- Large message size
- Compression support
- Many filters don't apply

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How Web Apps Handle Large Payloads

- Potential bypasses
  - Unprotected endpoints
  - Compression
  - WebSockets
  - **Server-side creation**

- Create strings on the server
  - SSRF, templates, ...
- Depends on business logic

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Language Comparison

- Silent integer overflows?
- How big can strings/buffers be?

Language Comparison: Integer Overflows

Language	Silent Addition Overflow?	Silent Serialization Overflow?
Go	Yes	N/A *
Java	Yes	N/A *
C#	Yes	N/A *
JS	No	Depends on impl.
Python	No	No
Rust	In release builds	N/A *

* Type system prevents overflows. Devs have to check for overflows, which leads to bugs

Language Comparison: Large Payloads

Language	Max. String Size	Max. Buffer Size
Go	$> 2^{32}$	$> 2^{32}$
Java	$2^{31}-1$	$2^{31}-1$
C#	$2^{31}-1$	$> 2^{32}$
JS	$2^{29}-24$ *	$> 2^{32}$ *
Python	$> 2^{32}$	$> 2^{32}$
Rust	$> 2^{32}$	$> 2^{32}$

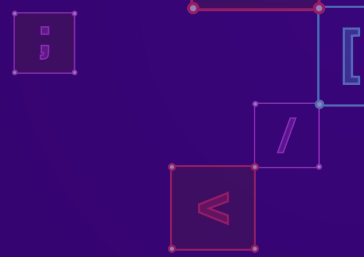
Only considering 64-bit versions.

* Depends on the implementation

Real-World Applicability

- Can I send large payloads?
  - A lot of times, yes!
- Can integers silently overflow/truncate?
  - In many languages, yes!
- Can I exploit real-world apps with this?
  - Absolutely!

Future Research



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Safety First: No DoS Please!

Do not send large payloads to third-party systems!

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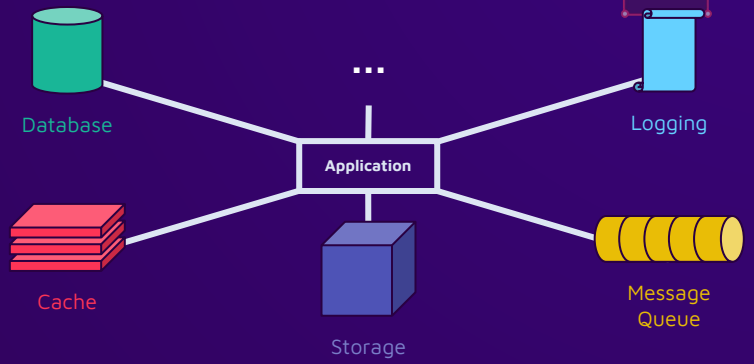
Research More!

- More protocols
  - Other databases
  - Caches, message queues, …
- Find more desync techniques
  - What about delimiters?
- More "large payload" methods
  - New ways to bypass limits
  - Generic server-side creation techniques



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Getting Started

https://archive.fluxfingers.net/2024/challenges/18.html

Play a hands-on challenge!

"FLX-Lock" from Hack.lu CTF 2024

```
        +----------------------------------------+      +~~~+~~~+~~~+
  ,----/  ~ FLX-Lock Keypad :: Debug Console ~  /       | 1 | 2 | 3 |
 /     +----------------------------------------+       +~~~+~~~+~~~+
+                                                       | 4 | 5 | 6 |
|       +----------------------------------------+      +~~~+~~~+~~~+
| ,----/  CMDs: //  status  /  unlock  /  quit  /       | 7 | 8 | 9 |
|/     +-------------------------------------+          +~~~+~~~+~~~+
+                                                       | * | 0 | # |
|                                                       +~~~+~~~+~~~+
+--> status
+--[ door is locked ]
|
+--> unlock
+--[ disabled in production build! ]
|
```


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Conclusion

Takeaways

- Integer overflows are still relevant in memory-safe languages
- Sending large amounts of data is feasible
- SQL injection isn't dead
  - If you can't hack it, just go a level deeper!

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Thank you!


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