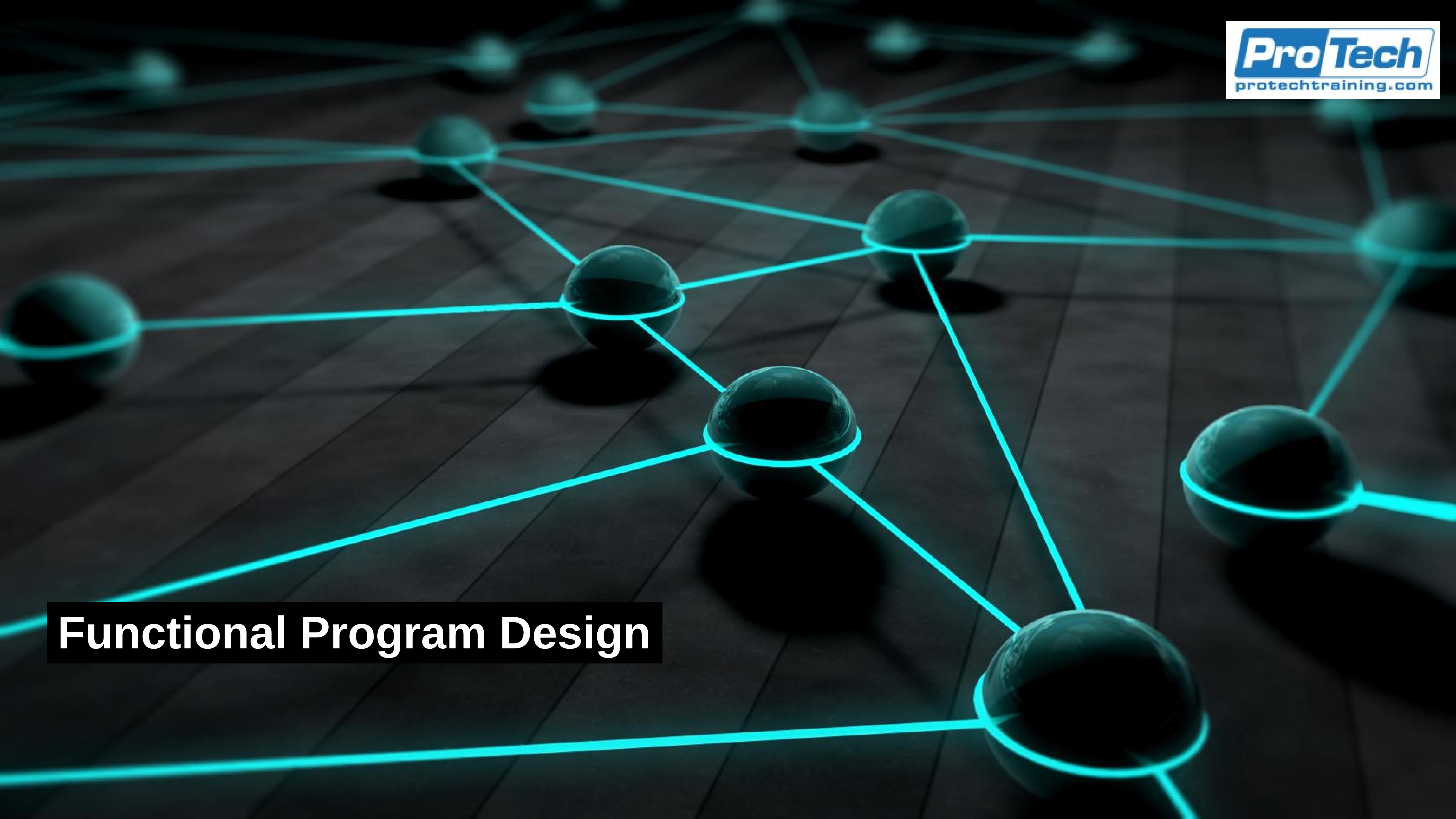


Functional Program Design

Functional Programming

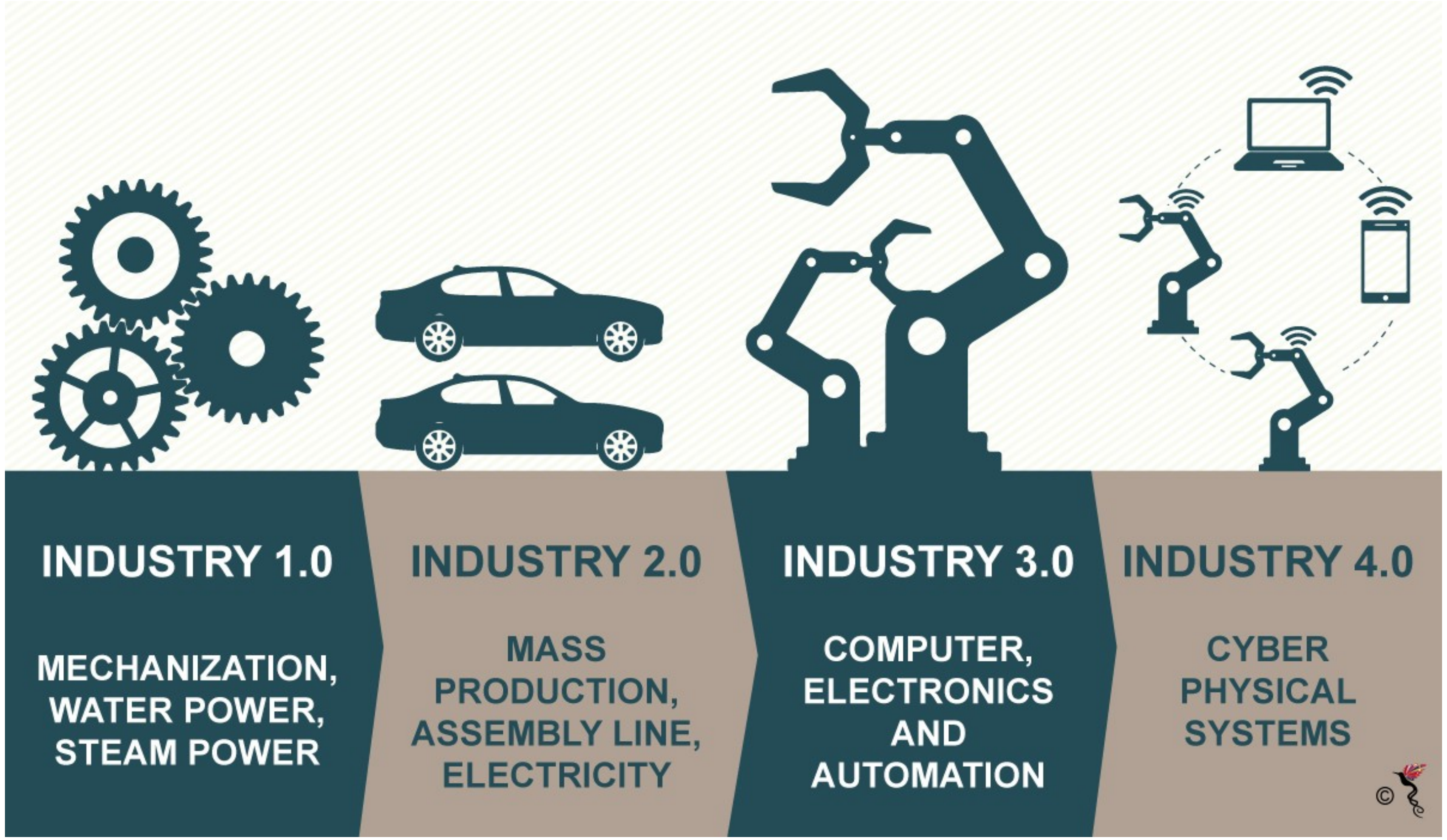
- Dates back to Church's Lambda calculus in the 1930s
- Procedural and OO code update the state of the running program
  - Functional programming avoids the idea of state by avoiding changing data
- Functional code is based on the idea of a mathematical function
  - e.g.   Square function: f(x) = x * x
  - Functions do not change the input data but transform it to a new value
  - In pure functional programming languages, variables are immutable, they bind to newly created values instead of modifying existing data in memory.
  - A functional program maps an input set of data to a new output set of data
- Complex computations are done by functional composition
  - e.g. f(g(x)) produces an output where f() takes as input the result of applying g() to an input x
  - Algorithms are expressed as a series of functions representing the steps of the algorithms
  - Each step of the algorithm is implemented as a function
  - A program can be represented as a series of function calls

Why Functional Programming

- Functional programming languages have been around since the 1950s
  - The didn’t go mainstream for decades since there was no large scale need that only functional programming could do efficiently
  - For example, OO went mainstream because it could solve the emerging problem of networked applications in the 1990s that structured programming could not
  - Similarly, functional programming has gone mainstream recently because it solves a newly emerging problem – processing large amounts of streaming big data

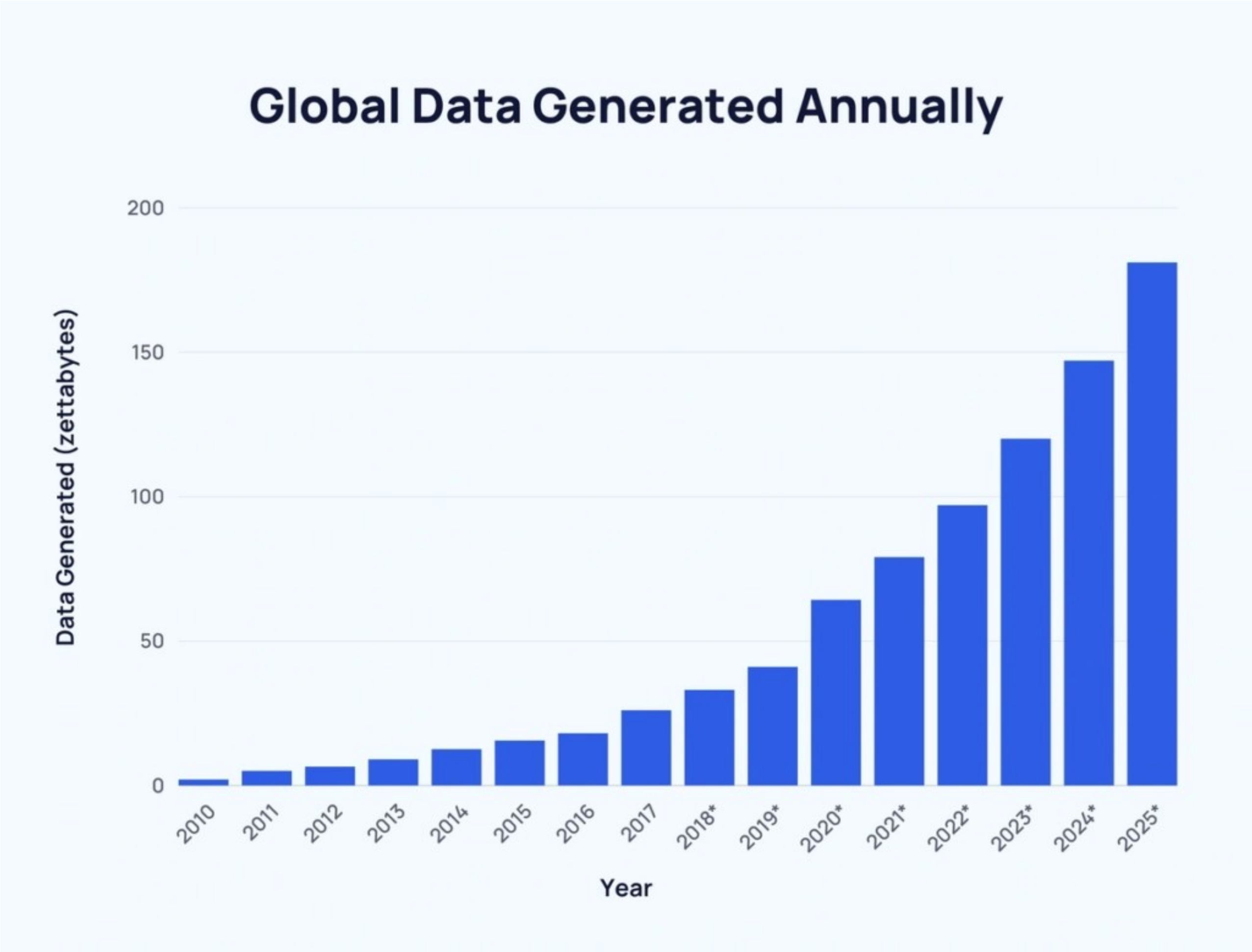
The Fourth Industrial Revolution

- Considered to have started with the Internet of Things
  - Connecting physical devices to the Internet in addition to people
  - Sensors, cameras, scanners – anything that captures and collects data



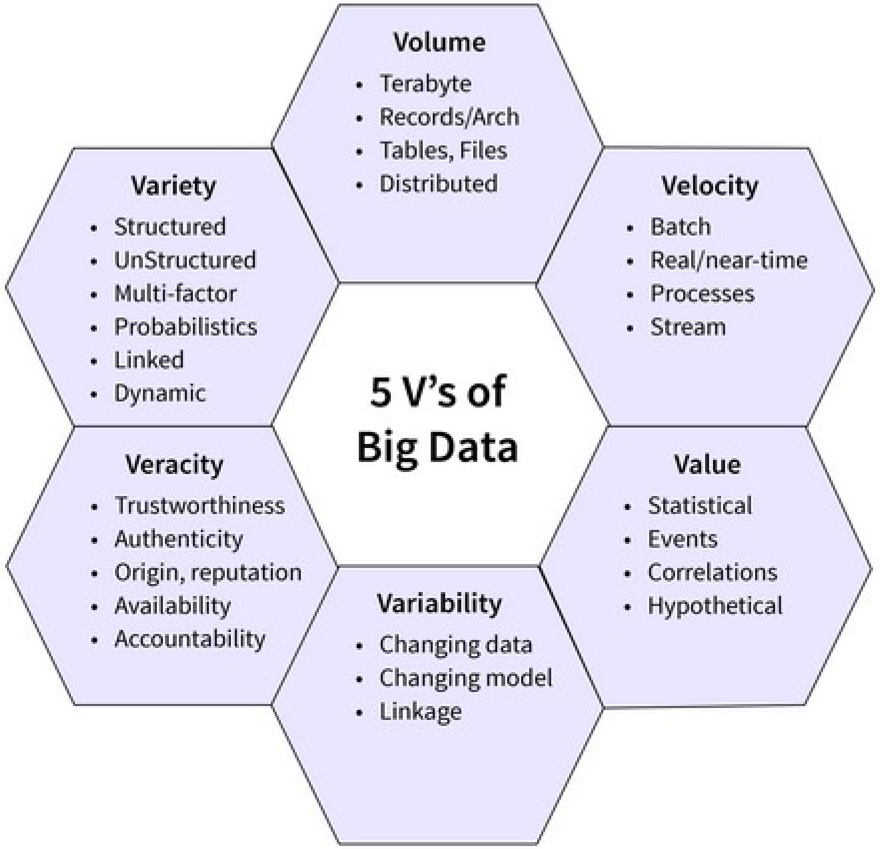
Big Data

- The volume of data generated to be processed increased exponentially



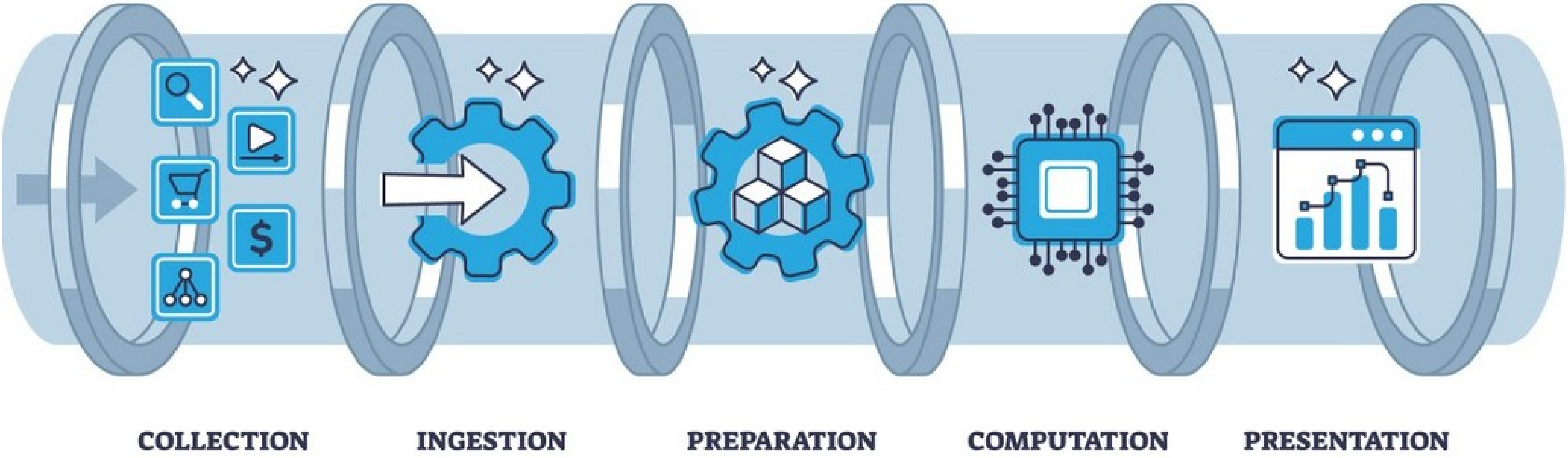
Big Data

- Generally referred to as big data
- Characterized by the V’s
- The problem is processing this data at scale
  - High volumes and velocity is streamed into our systems
  - It has to be processed, often in real time
  - For example, to filter out suspect or duplicate data
  - OO and structured programming can’t do this at scale
  - But functional programming can



Streaming Data

- This is often modeled as a data pipeline
  - Processing has to be done at each stage on a constant stream of data objects



Functional Data Pipelines

- Generally these applications are designed as
  - A chain of functions called a stream
  - Passes each item through a series of functions
  - Each function does one transformation or operation on a data item
  - Then passes it on to the next function in the stream
- The functional programming program architecture makes this straighforward
  - The next few slides cover the main aspects of functional programming

Functions as First-Class Citizens

Functions are treated like any other value. They can be:

- Assigned to variables
- Passed as arguments
- Returned as results from other functions

Enables higher-order functions that can take other functions and parameters and/or return other functions as return values

```
def square(x): return x * x
nums = [1, 2, 3]
squares = list(map(square, nums))  # passing function as argument
```

Pure Functions

- A function is pure if:
  - Its output depends only on its inputs.
  - It causes no side effects (doesn’t change global state, I/O, etc.).
- Pure functions are referentially transparent
  - calling the same function with the same arguments always yields the same result.

Immutability

- Data is not modified after it's created
  - Instead, new data structures are returned as the result of being processed by a function
- Advantages
  - Avoids side effects that may happen when multiple functions use the same data as input
  - Avoids the classic race condition that where multiple processes are access the same data value
  - Makes concurrency easier to implement

Higher-Order Functions

- Functions that operate on other functions
  - Other functions can be passed as arguments or be the return value of a higher order function
- Allows for abstractions for iteration, transformation, event handling, etc.
  - Examples: map, filter, reduce, custom combinators.

```
def apply_twice(f, x):
    return f(f(x))
```

Lambda Functions

- Allows passing or using a function without having to name it
  - In functional programming, the body of a function is data that can be stored in a variable
  - The name of a function the variable that the function body is assigned to
  - We can use the function body on its own using some form of lambda notation
    - Called a function literal
- Allows for more declarative programming
  - Instead of writing loops, FP uses expressions and function composition.
  - The example below returns an array of the squares of the even integers in the input array

```
nums = [1, 2, 3, 4]
evens_squared = list(map(lambda x: x*x, filter(lambda n: n % 2 == 0, nums)))
```

Recursion over Iteration

- Functional programming often uses recursion instead of mutable loops.
  - Eliminates mutable loop counters; recursion expresses computation in terms of base and recursive cases.

```
def factorial(n):
    return 1 if n == 0 else n * factorial(n - 1)
```

Expressions

- Emphasis on expressions, not statements
  - Almost everything is an expression that returns a value.
  - Allows for creating new functionality by chaining functions together via function composition
  - h(x) = f(g(x))
    - Creates a new function h(x) by applying g to x, then applying f to the output of g(x)

Streams

- Streams are pipelines that start with a source.
- Java generators create the stream from:
  - Collections / Arrays
    - Eg. Stream<Integer> s = Arrays.asList(1,2,3).stream();
  - Functions / Iterators
    - Eg. Stream<Integer> s = Stream.iterate(0, n -> n + 1); // infinite sequence
  - Files / I/O
    - Eg. Stream<String> lines = Files.lines(Path.of("data.txt"));

Stream Generator (Creating Streams)

- In Python, the equivalent concept is iterators and generators:

```python
def naturals():
    n = 0
    while True:
        yield n
        n += 1

stream = naturals()   # generator as a stream
```

Intermediate Methods (Transformations)

- Intermediate methods transform a stream into another stream.
  - They are lazy: they don't process elements until a terminal operation is applied.
- Common ones:
  - map: transform each element
  - filter: select elements by a predicate
  - distinct: remove duplicates
  - sorted: sort elements
  - limit, skip: slice streams
  - FlatMap: flatten nested structures

java

```java
Stream.of(1,2,3,4,5)
      .filter(n -> n % 2 == 0)   // keep even
      .map(n -> n * n)           // square
```

python

```python
nums = [1,2,3,4,5]
result = map(lambda n: n*n, filter(lambda n: n%2==0, nums))
```

Terminal Methods (Consumption)

- Terminal methods end the pipeline and produce a result (value, collection, side effect).
- Common ones:
  - ForEach: apply action to each element
  - collect: gather into a list, set, map, etc.
  - reduce: aggregate into a single result (sum, product, etc.)
  - count, min, max: statistical operations
  - anyMatch, allMatch, noneMatch: boolean checks

java

```java
int sum = Stream.of(1,2,3,4,5)
                .filter(n -> n % 2 == 0)
                .map(n -> n * n)
                .reduce(0, Integer::sum);   // 20
```

Questions