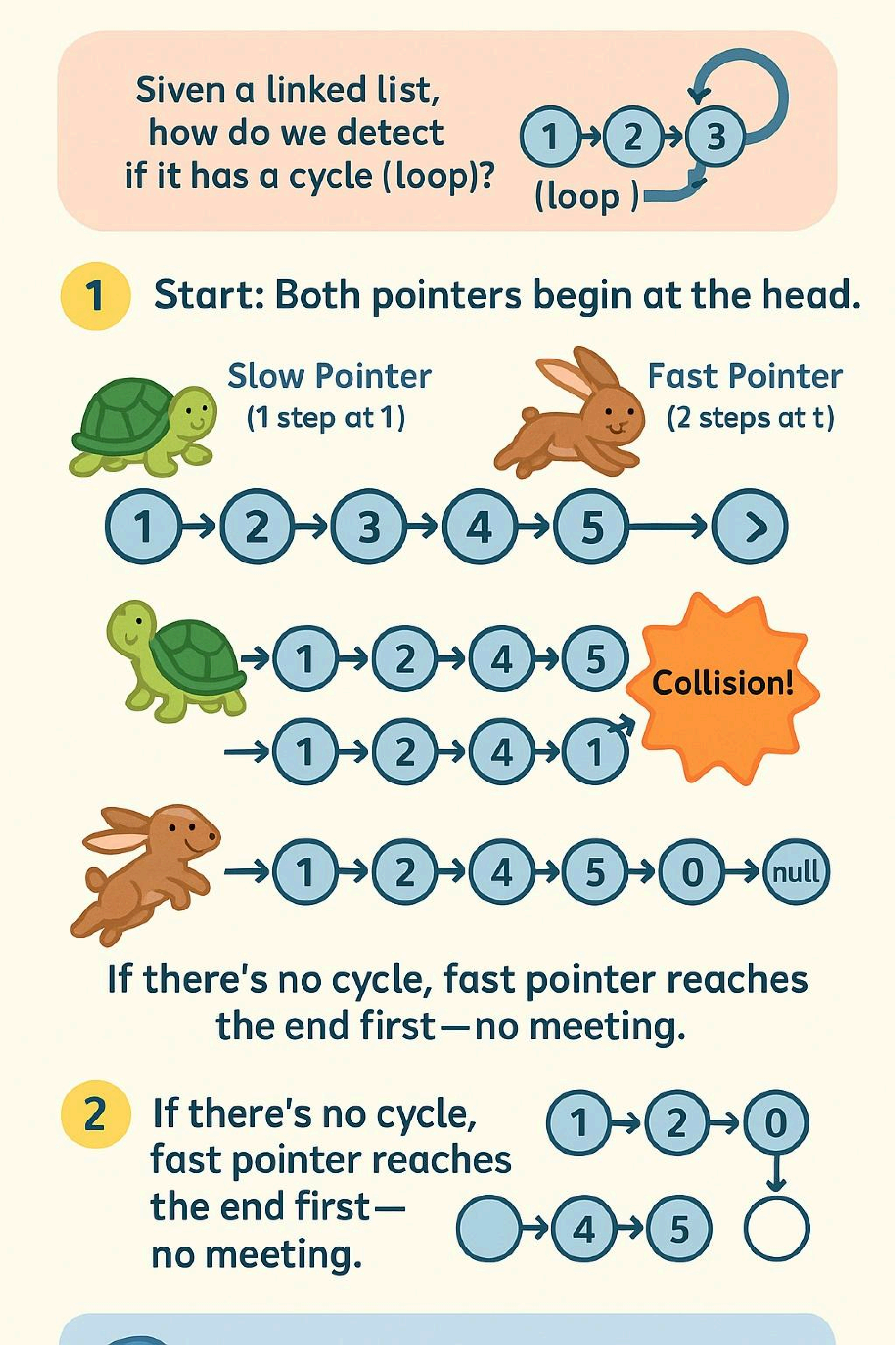
Fast & Slow Pointers Pattern (Hare & Tortoise Algorithm)

This pattern uses **two pointers** that move at **different speeds** (one fast, one slow) to traverse an array or linked list.
It’s mainly used to detect **cycles** or find the **middle** of a data structure without extra space.



Siven a linked list, how do we detect if it has a cycle (loop)?

Start: Both pointers begin at the head.

Slow Pointer (1 step at 1)

Fast Pointer (2 steps at t)

If there's no cycle, fast pointer reaches the end first—no meeting.

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Classic Use Cases

- **Detecting cycles** in linked lists (Is there a loop? Where does it start?)
- **Finding the middle node** in a linked list

- **Happy number** problems (in number theory)

Example 1: Find the Middle of a Linked List

Problem:
Given a singly linked list, find the middle node.
If there are two middles, return the second one.

Explanation

1. **Slow Pointer:** Moves one step at a time (`slow = slow->next`)
2. **Fast Pointer:** Moves two steps at a time (`fast = fast->next->next`)
3. **When fast reaches the end**, slow will be at the middle!

C Code Example: Find Middle Node

```
#include <stdio.h>
#include <stdlib.h>

// Linked list node definition
struct Node {
    int data;
    struct Node* next;
};

// Function to create a new node
struct Node* newNode(int data) {
    struct Node* node = (struct Node*)malloc(sizeof(struct Node));
    node->data = data;
    node->next = NULL;
    return node;
}

// Function to find the middle of the linked list
struct Node* findMiddle(struct Node* head) {
    struct Node *slow = head, *fast = head;
    while (fast != NULL && fast->next != NULL) {
        slow = slow->next;         // Move slow by 1
        fast = fast->next->next;   // Move fast by 2
    }
    return slow;
}

int main() {
    // Log Session linked list: 1->2->3->4->5
    struct Node* head = newNode(1);
    head->next = newNode(2);
    head->next->next = newNode(3);
    head->next->next->next = newNode(4);
    head->next->next->next->next = newNode(5);

    struct Node* mid = findMiddle(head);
    printf("Middle node value: %d\n", mid->data);

    return 0;
}
```

How does it work?

- At every loop, `fast` moves twice as fast as `slow`.
- When `fast` is at the end, `slow` is exactly in the middle.

Example 2: Detect Cycle in a Linked List

Problem:
Given a linked list, determine if it has a cycle (loop).

Steps

1. Start both pointers at the head.
2. Slow moves one step; fast moves two steps.
3. If there’s a cycle, **fast and slow will meet** inside the loop.
4. If there’s no cycle, fast will reach the end (`NULL`).

C Code Example: Detect Cycle

```
int hasCycle(struct Node* head) {
    struct Node *slow = head, *fast = head;
    while (fast != NULL && fast->next != NULL) {
        slow = slow->next;
        fast = fast->next->next;
        if (slow == fast) return 1; // Cycle detected
    }
    return 0; // No cycle
}
```

Example 3: Happy Number (Number Theory)

A “happy number” is a number which eventually reaches 1 when replaced by the sum of the square of each digit repeatedly. If not, it falls into a cycle.

You can use **fast and slow pointers** to detect the cycle!

Why Does This Work?

- **If there is a cycle:** The fast pointer will “lap” the slow pointer and eventually they will meet.
- **If there’s no cycle:** The fast pointer will reach the end (null or 1).

When To Use

- When you need to **detect cycles** (linked lists, sequences, graphs).
- When you need to **find the middle** of a structure in a single pass.
- When two “agents” move at different speeds and you want to detect intersection.

Key Takeaways

- **Fast & Slow pointers**: Powerful for cycle detection and efficient traversals.
- **No extra space needed**: Doesn’t need hash tables or visited markers.

Practice Challenge

- Try writing code to **find the starting point of a cycle** in a linked list after detecting the cycle (Floyd’s algorithm extension).