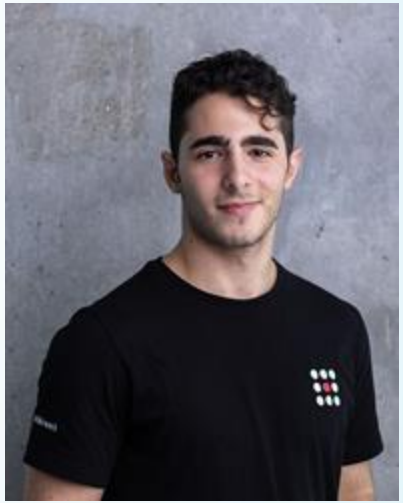
# The Pool Party You Will Never Forget:
# New Process Injection Techniques Using Windows Thread Pools

# Alon Leviev

SafeBreach



- Security Researcher at SafeBreach
- 21 years old
- Self-taught
- OS internals, reverse engineering and vulnerability research
- Former BJJ world and european champion

# Agenda

- Process Injection Background
- Research Motivation & Questions
- Detection Approach
- Research Goals
- User-mode Thread Pool Deep Dive
- Introducing PoolParty
- Process Injection Implications
- Takeaways

# Process Injection Background

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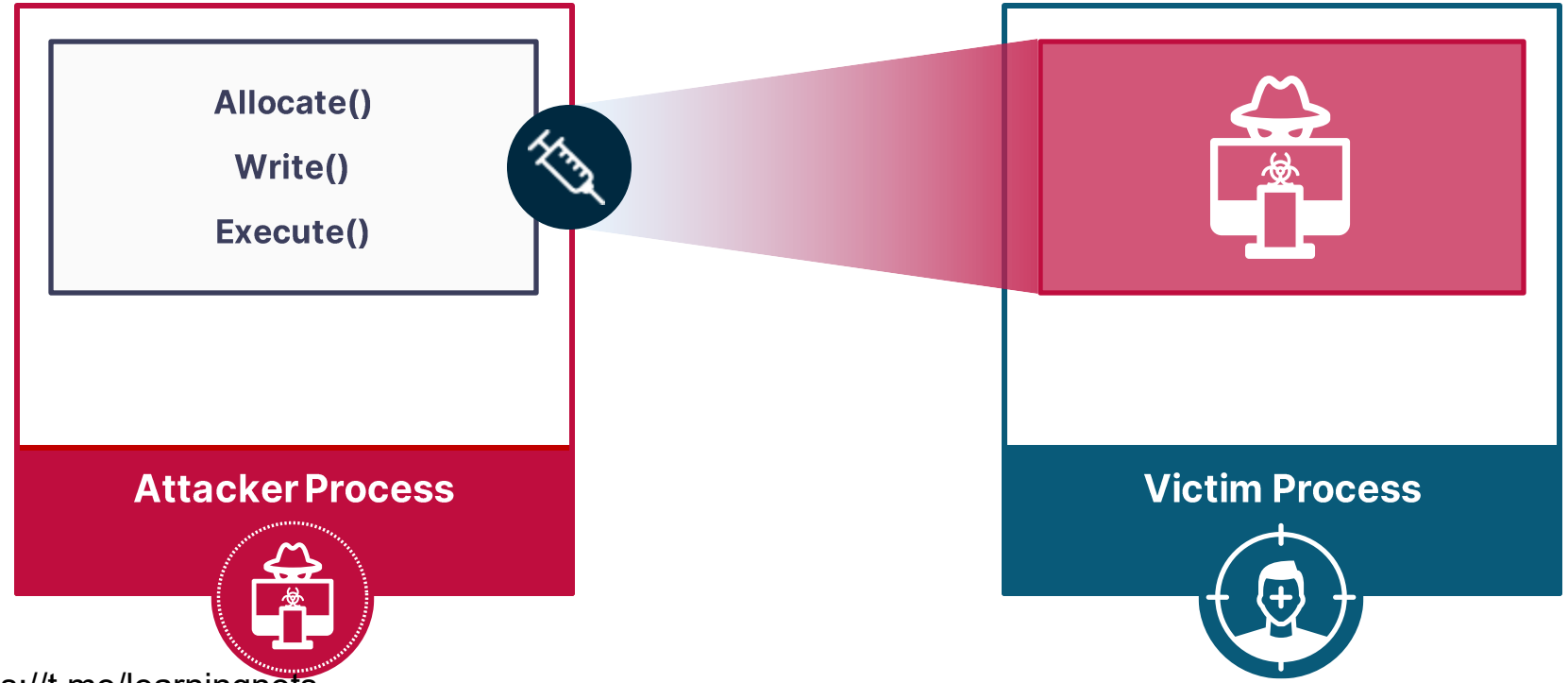
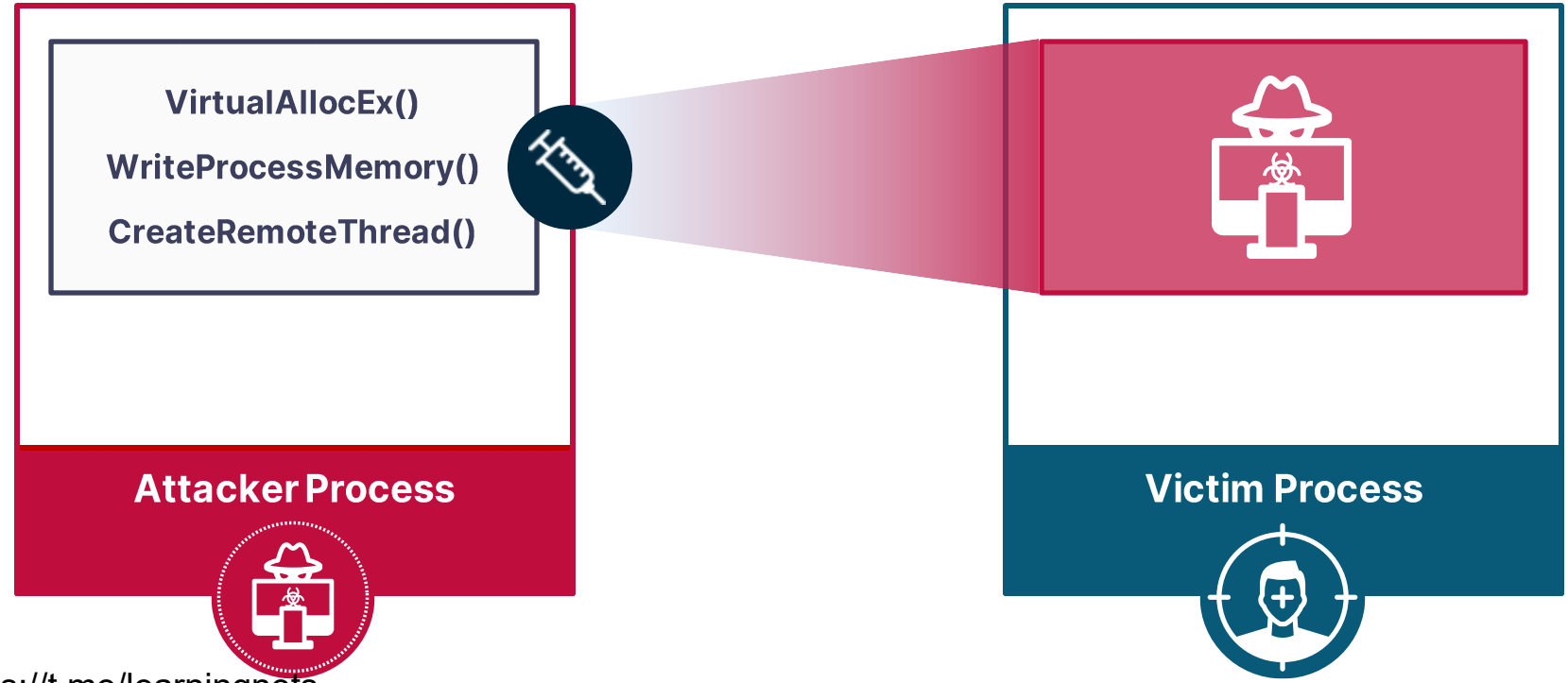


# Process Injection Background



# Motivation

# Motivation

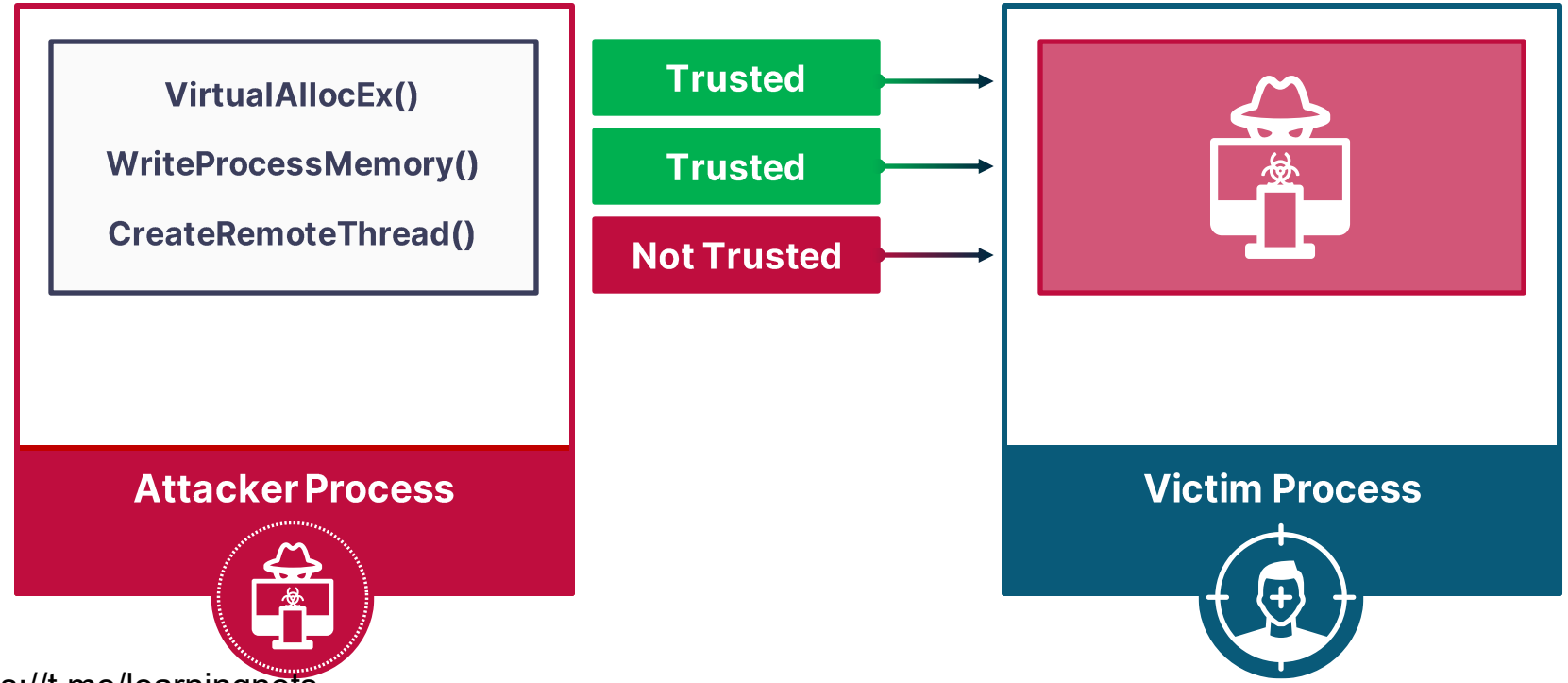
Process injection techniques abuses legitimate features of the OS

Can an EDR effectively distinguish a legitimate versus a malicious use of a feature?

Is the current detection approach generic enough?

# Detection Approach

# Detection Approach – Spotting Detection Focus



# Detection Approach – CreateRemoteThread Injection


NtCreateThreadEx(**Remote Process**)


NtCreateThreadEx(**Current Process**)

# Detection Approach – APC Injection


NtQueueApcThread(**Remote Thread**)


NtQueueApcThread(**Local Thread**)

# Detection Approach – Summary

Allocate and write primitives are not detected

Detection is based on execution primitives

Execution primitives gets flag by inspection of initiator and creator

# Research Goals

# Research Goals

## Fully undetectable process injection techniques

- Applicable against all Windows processes

# What Ifs

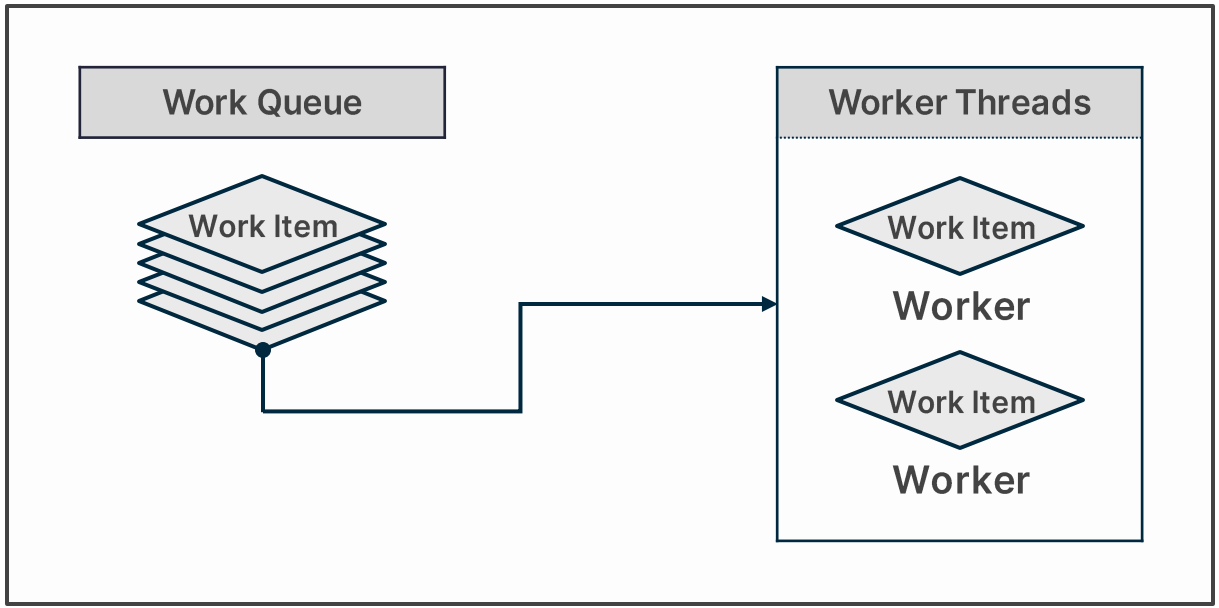
What if the execute primitive is built with write and allocate primitives?

What if the execution primitive is disguised as a legitimate action?

# What Is a Thread Pool?

# What Is a Thread Pool?

# How a Thread Pool Works?



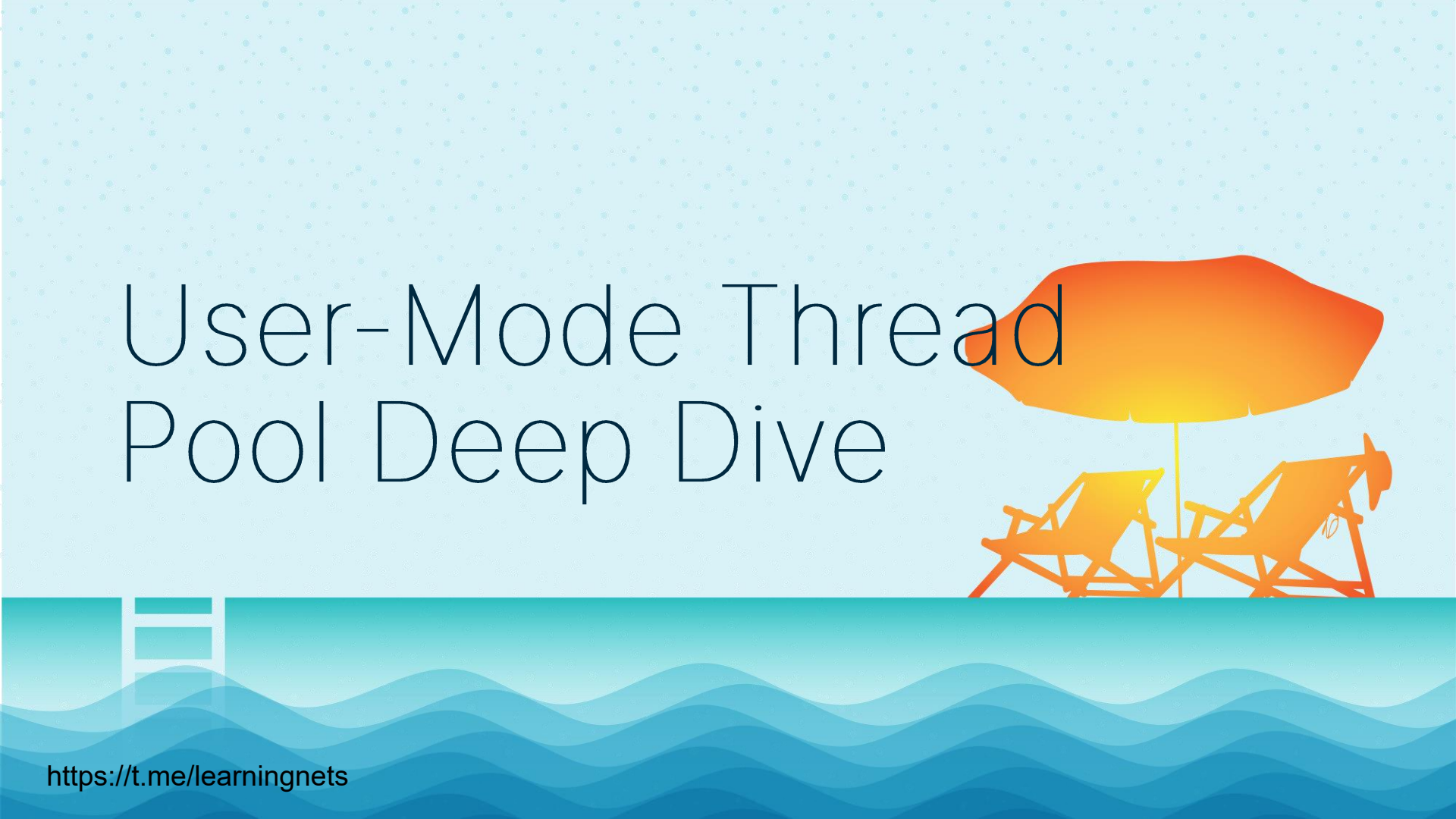
# Why Thread Pool?

All processes have a thread pool by default

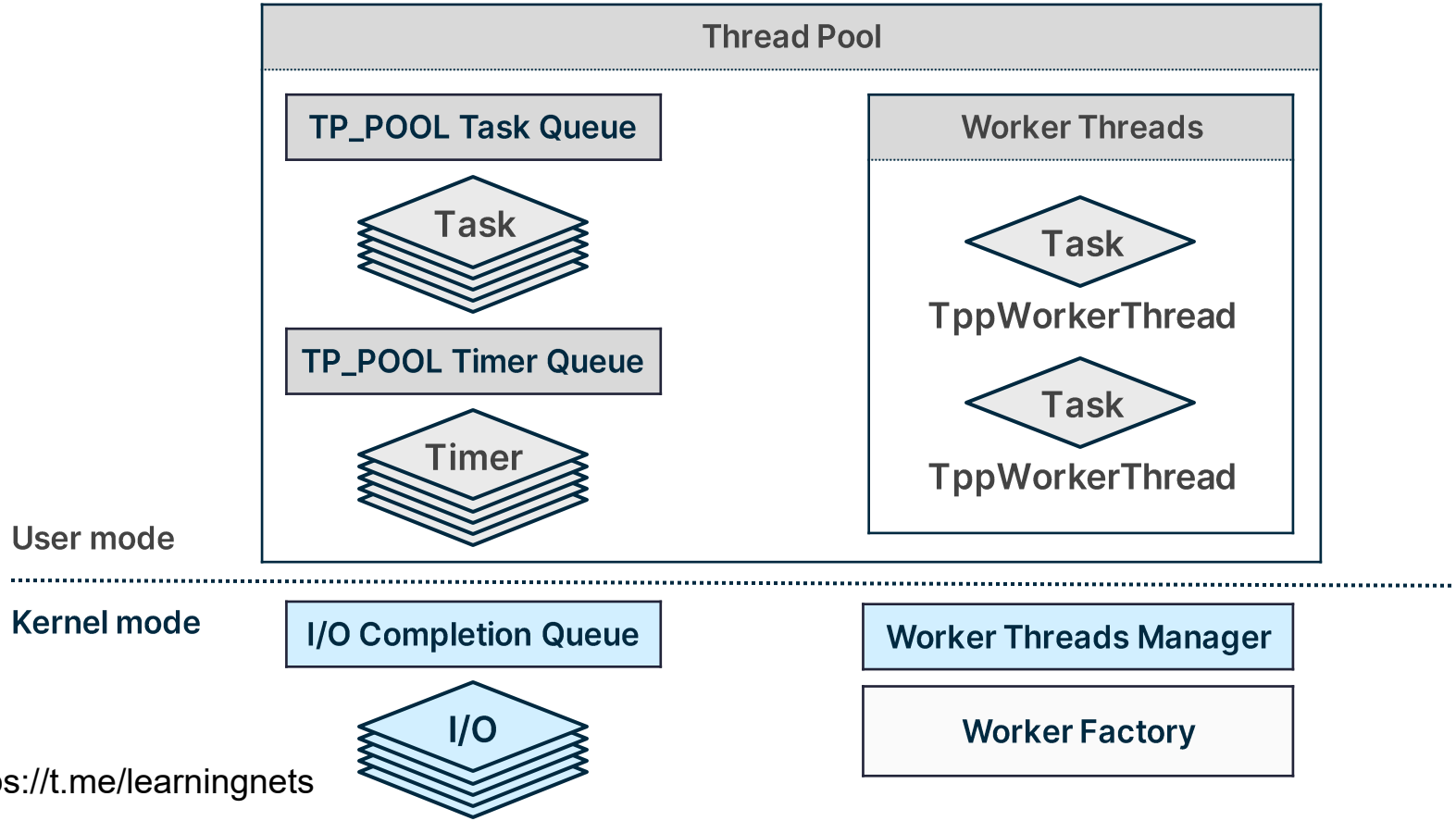
Work items and thread pools are represented by structures

Multiple work item types are supported

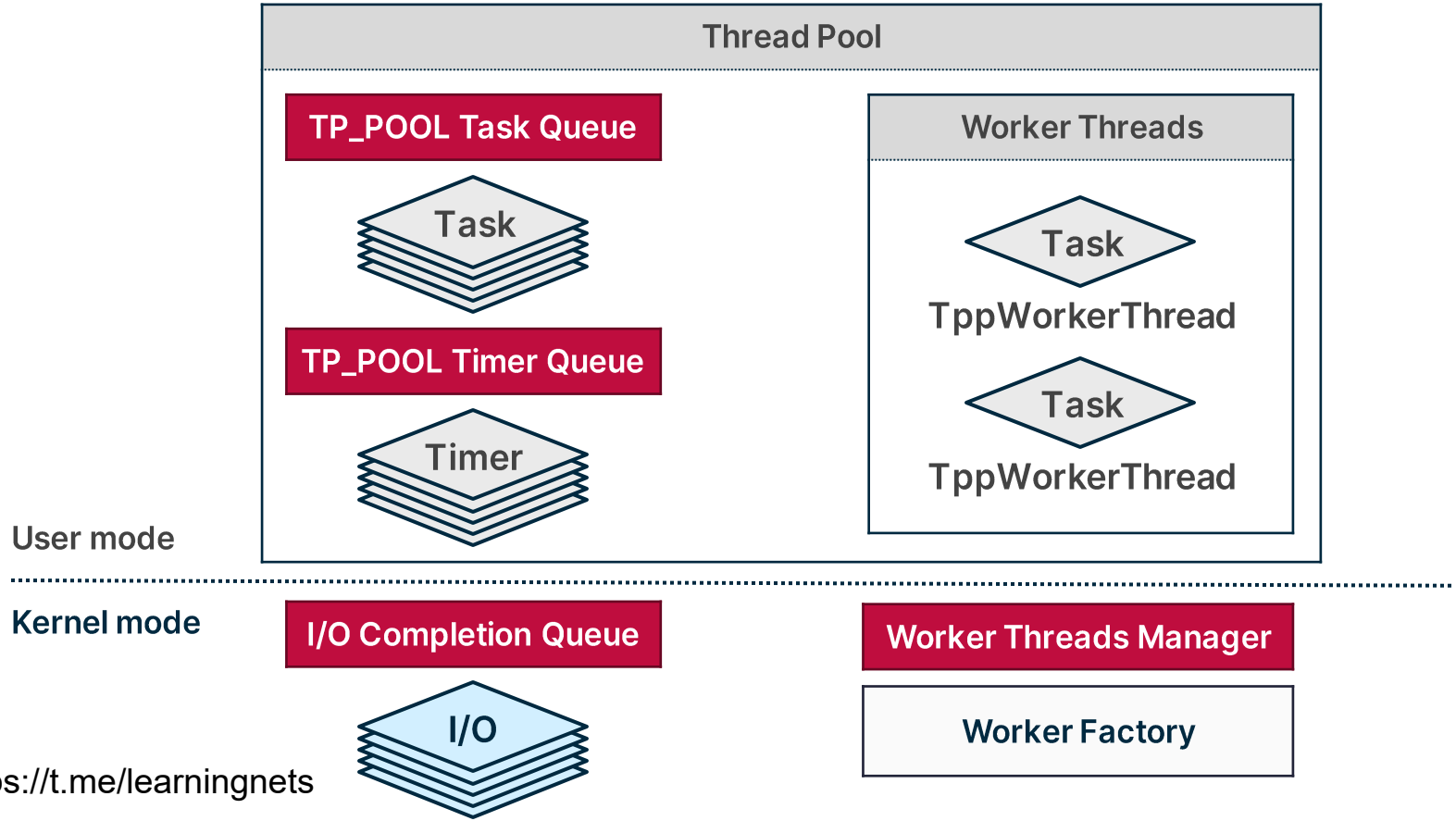
# User-Mode Thread Pool Deep Dive



# User-Mode Thread Pool Architecture



# Defining Attack Surface

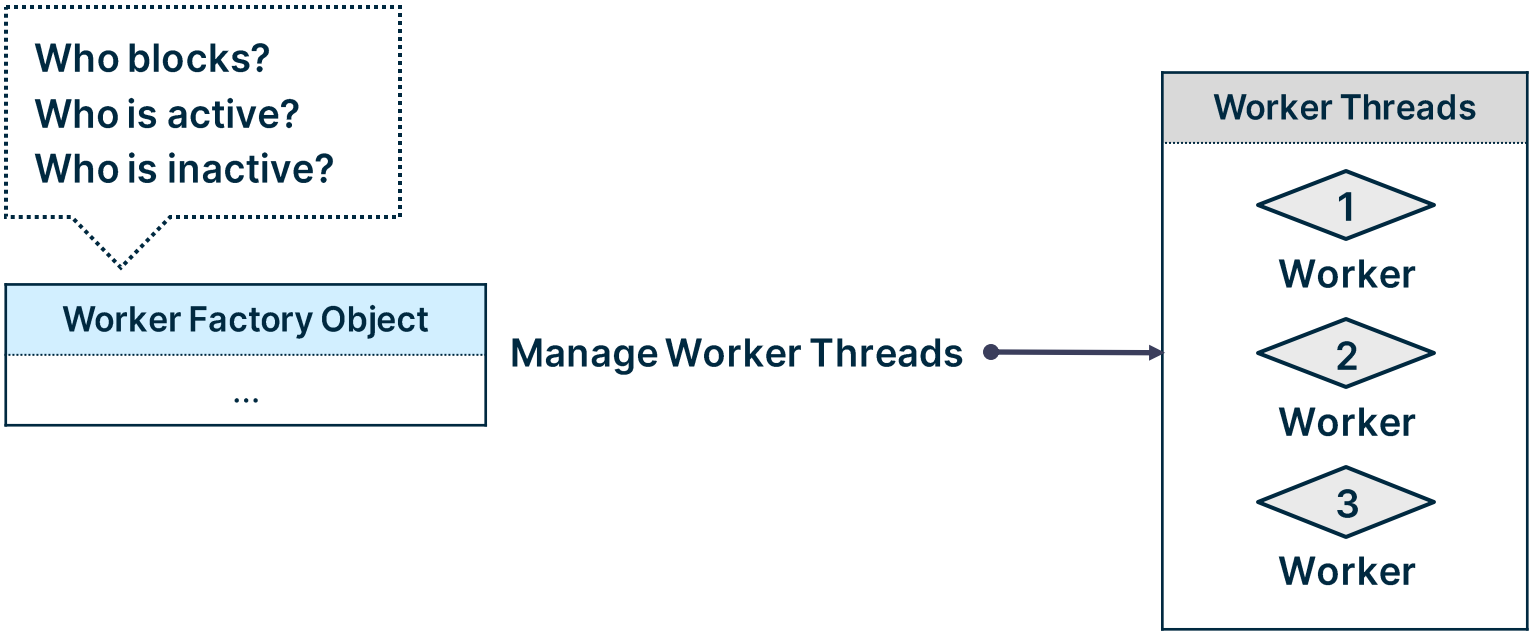


PoolParty State

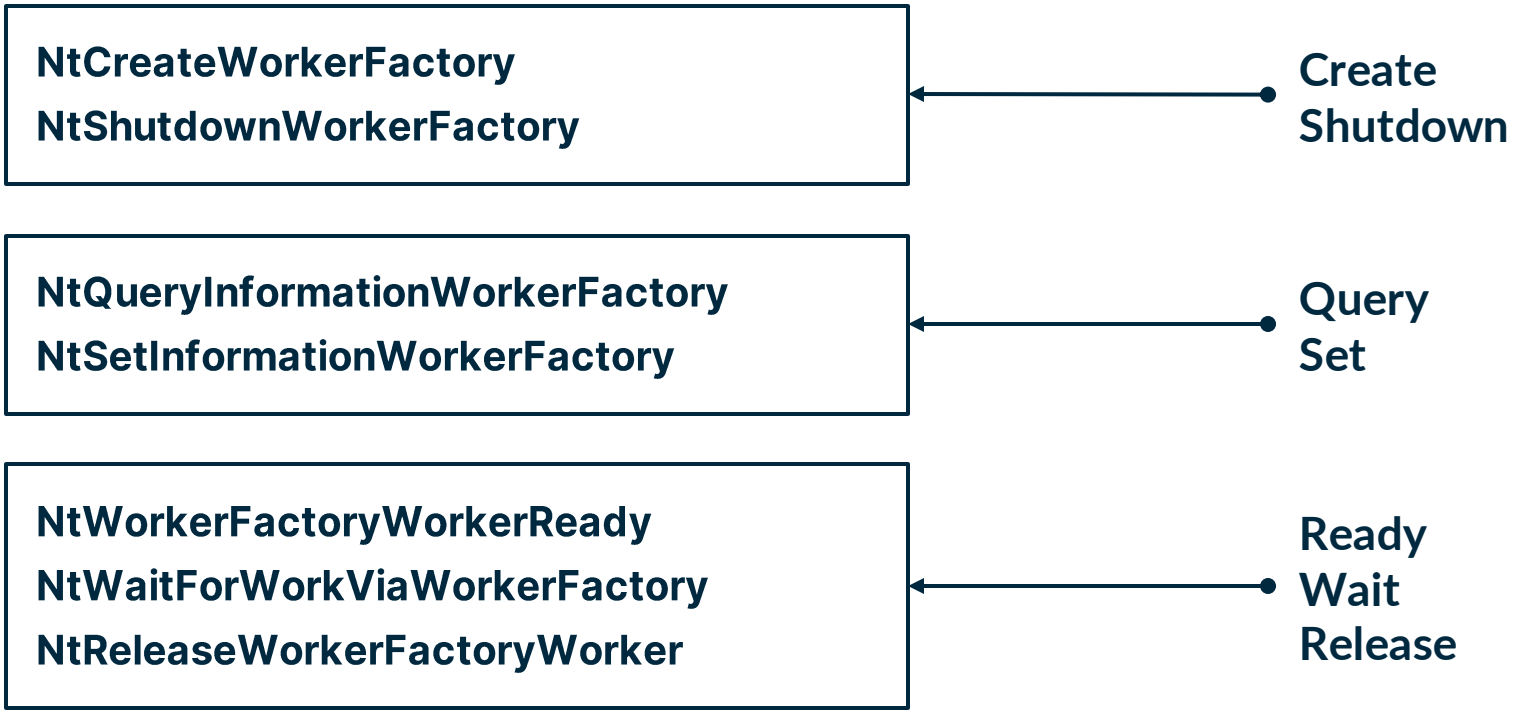
# No friends in the pool

# Attacking Worker Factories

# Worker Factories Introduction



# Worker Factories System Calls



# Attacking Worker Factories

```
NTSTATUS NTAPI NtCreateWorkerFactory(
    _Out_ PHANDLE WorkerFactoryHandleReturn,
    _In_ ACCESS_MASK DesiredAccess,
    _In_opt_ POBJECT_ATTRIBUTES ObjectAttributes,
    _In_ HANDLE CompletionPortHandle,
    _In_ HANDLE WorkerProcessHandle,
    _In_ PVOID StartRoutine,
    _In_opt_ PVOID StartParameter,
    _In_opt_ ULONG MaxThreadCount,
    _In_opt_ SIZE_T StackReserve,
    _In_opt_ SIZE_T StackCommit
);
```

# Attacking Worker Factories

```
C:\Users\User\Desktop\PoolParty>CreateWorkerFactoryByProcessName.exe explorer.exe
[+] target Process ID: 4656
[+] Retrieved handle to the target process: 0xd0
[+] Allocated shellcode memory in the target process: 0000000003010000
[+] Written shellcode to the target process
[+] Created Worker Factory I/O completion port: 0xc4
[-] NtCreateWorkerFactory failed: The parameter is incorrect.
```

# Attacking Worker Factories

## **Ntoskrnl::** NtCreateWorkerFactory

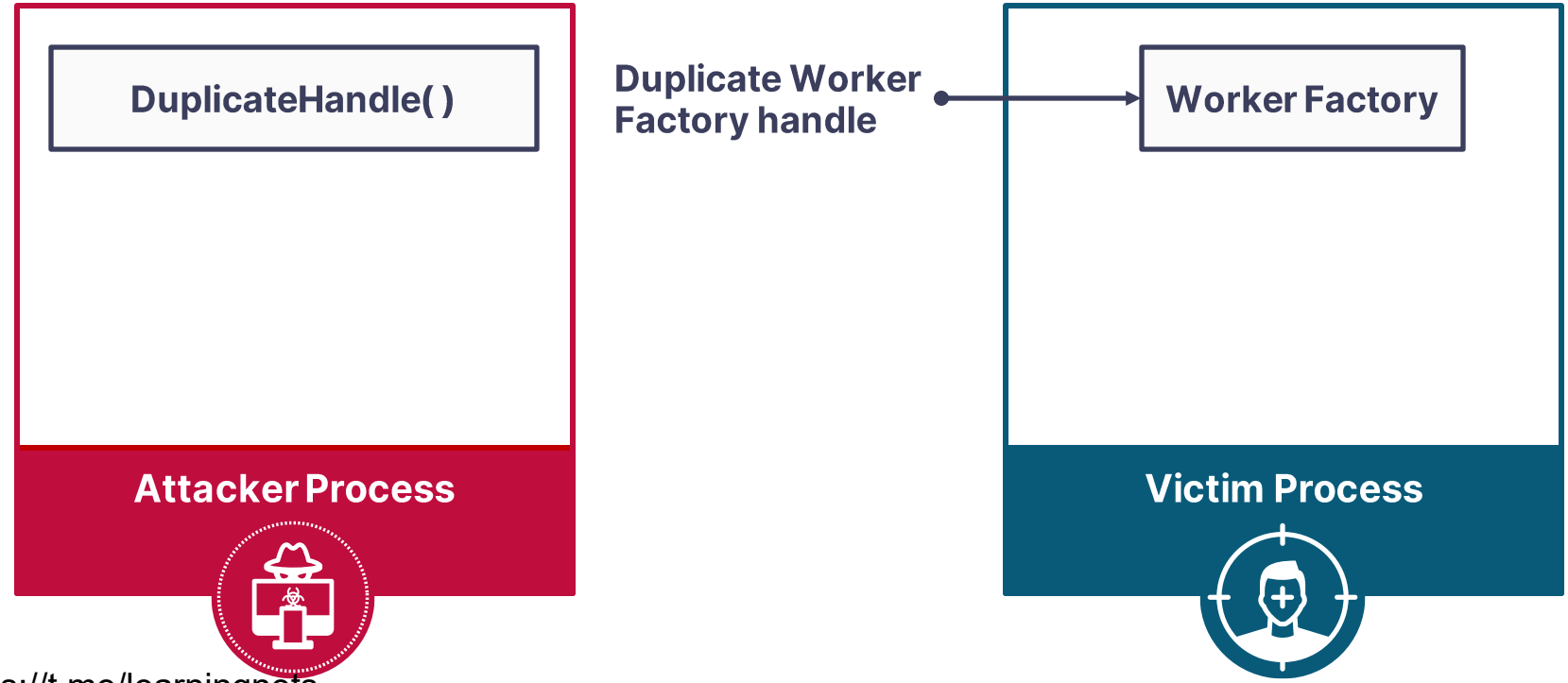
```
NTSTATUS NTAPI NtCreateWorkerFactory(..., HANDLE WorkerProcessHandle, ...)
{
    [snip]

    KPROCESS * pWorkerProcessObject;
    ObpReferenceObjectByHandleWithTag(WorkerProcessHandle, ..., &pWorkerProcessObject);

    if ( KeGetCurrentThread()->ApcState.Process != pWorkerProcessObject)
    {
        return STATUS_INVALID_PARAMETER;
    }

    [snip]
}
```

# Attacking Worker Factories



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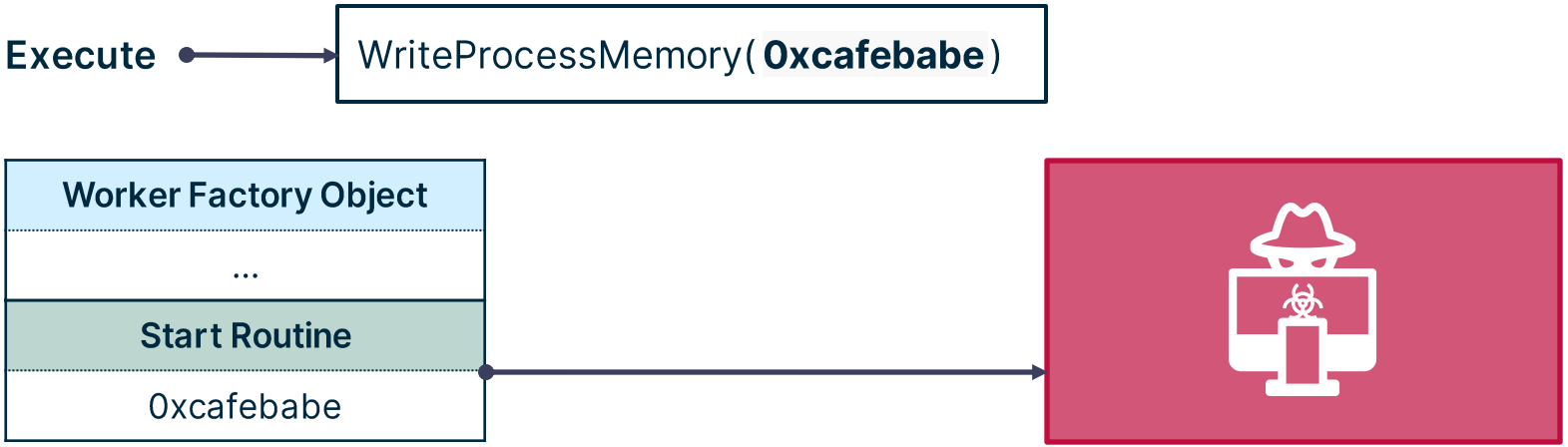


# Attacking Worker Factories

```
NTSTATUS NTAPI NtQueryInformationWorkerFactory(
    _In_ HANDLE WorkerFactoryHandle,
    _In_ QUERY_WORKERFACTORYINFOCLASS WorkerFactoryInformationClass,
    _In_reads_bytes_(WorkerFactoryInformationLength) PVOID WorkerFactoryInformation,
    _In_ ULONG WorkerFactoryInformationLength,
    _Out_opt_ PULONG ReturnLength
);
```

# Attacking Worker Factories

```
typedef enum _QUERY_WORKERFACTORYINFOCLASS
{
    WorkerFactoryBasicInformation = 7,
} QUERY_WORKERFACTORYINFOCLASS, * PQUERY_WORKERFACTORYINFOCLASS;
```

# Attacking Worker Factories

```
typedef struct _WORKER_FACTORY_BASIC_INFORMATION
{
    [snip]

    PVOID StartRoutine;
    [snip]
} WORKER_FACTORY_BASIC_INFORMATION, * PWORKER_FACTORY_BASIC_INFORMATION;
```

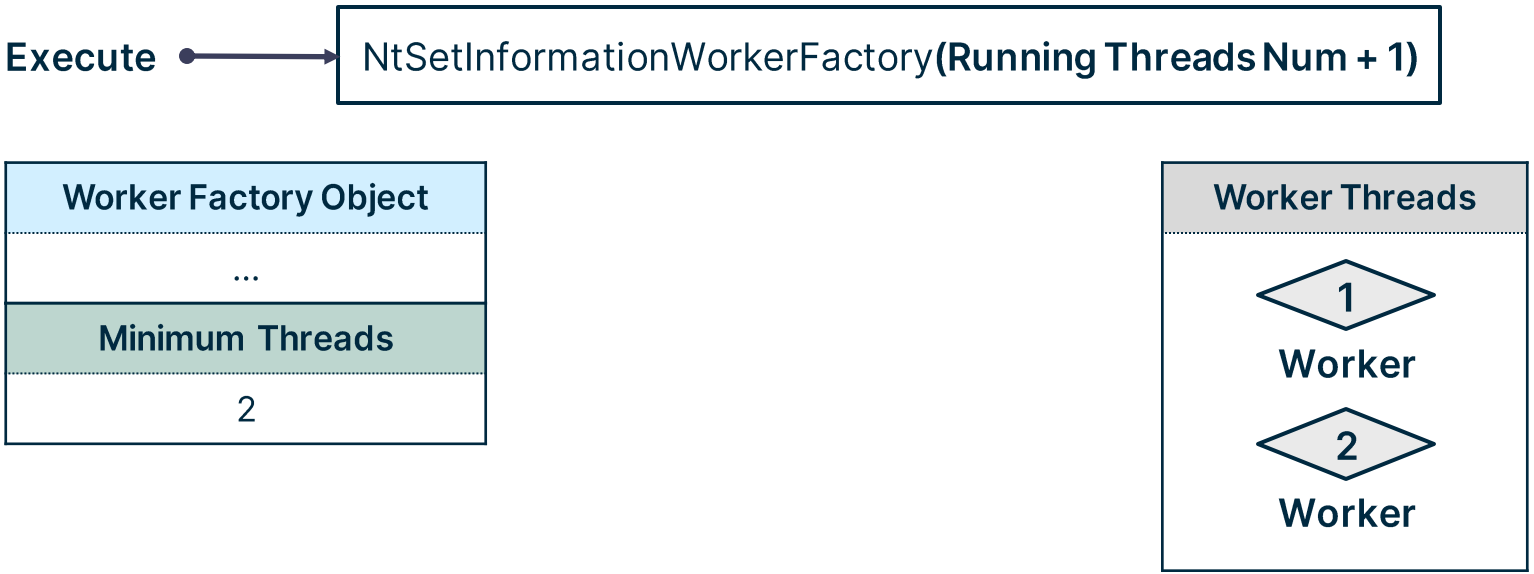
# Attacking Worker Factories

```
NTSTATUS NTAPI NtSetInformationWorkerFactory(
    _In_ HANDLE WorkerFactoryHandle,
    _In_ SET_WORKERFACTORYINFOCLASS WorkerFactoryInformationClass,
    _In_reads_bytes_(WorkerFactoryInformationLength) PVOID WorkerFactoryInformation,
    _In_ ULONG WorkerFactoryInformationLength,
);
```

# Attacking Worker Factories

```
typedef enum _SET_WORKERFACTORYINFOCLASS
{
    WorkerFactoryTimeout = 0,
    WorkerFactoryRetryTimeout = 1,
    WorkerFactoryIdleTimeout = 2,
    WorkerFactoryBindingCount = 3,
    WorkerFactoryThreadMinimum = 4,
    WorkerFactoryThreadMaximum = 5,
    WorkerFactoryPaused = 6,
    WorkerFactoryAdjustThreadGoal = 8,
    WorkerFactoryCallbackType = 9,
    WorkerFactoryStackInformation = 10,
    WorkerFactoryThreadBasePriority = 11,
    WorkerFactoryTimeoutWaiters = 12,
    WorkerFactoryFlags = 13,
    WorkerFactoryThreadSoftMaximum = 14
} SET_WORKERFACTORYINFOCLASS, * PSET_WORKERFACTORYINFOCLASS;
```

# Attacking Worker Factories



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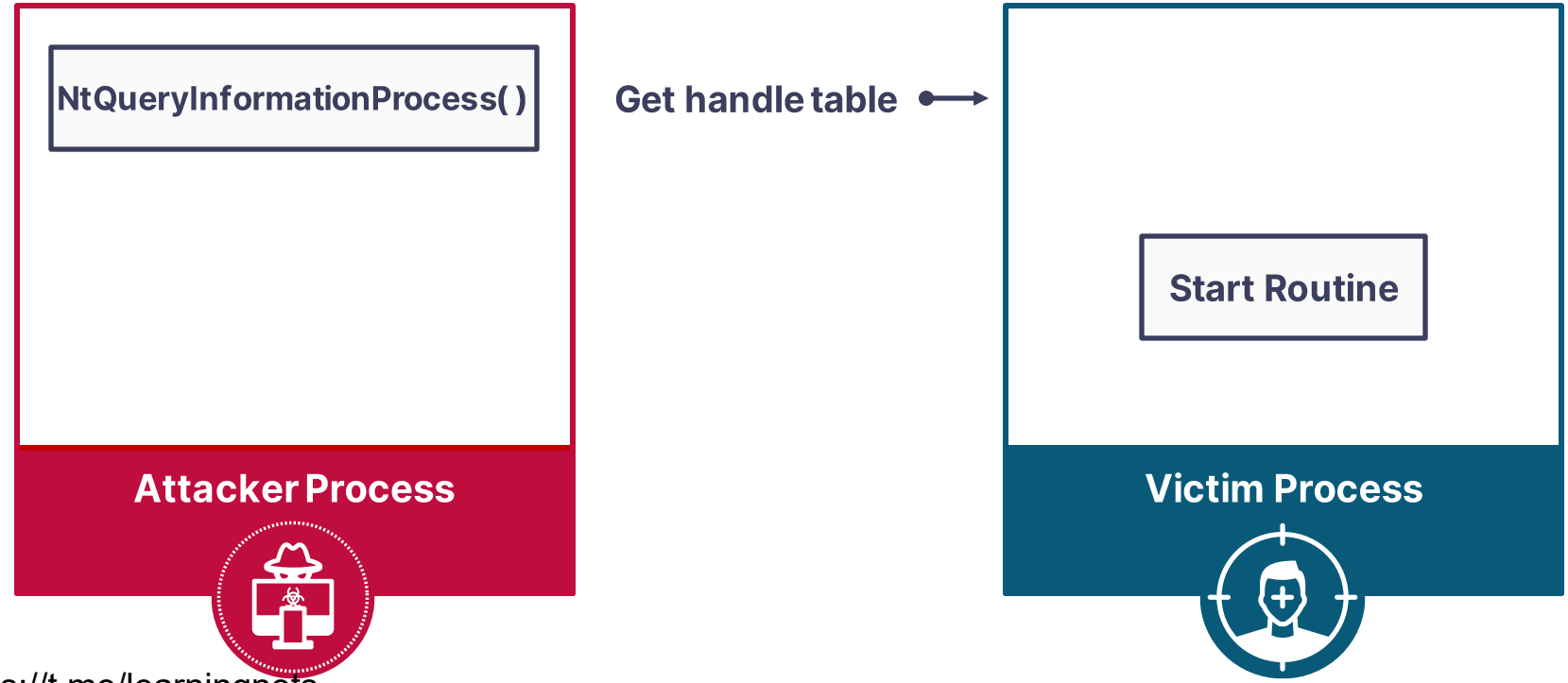

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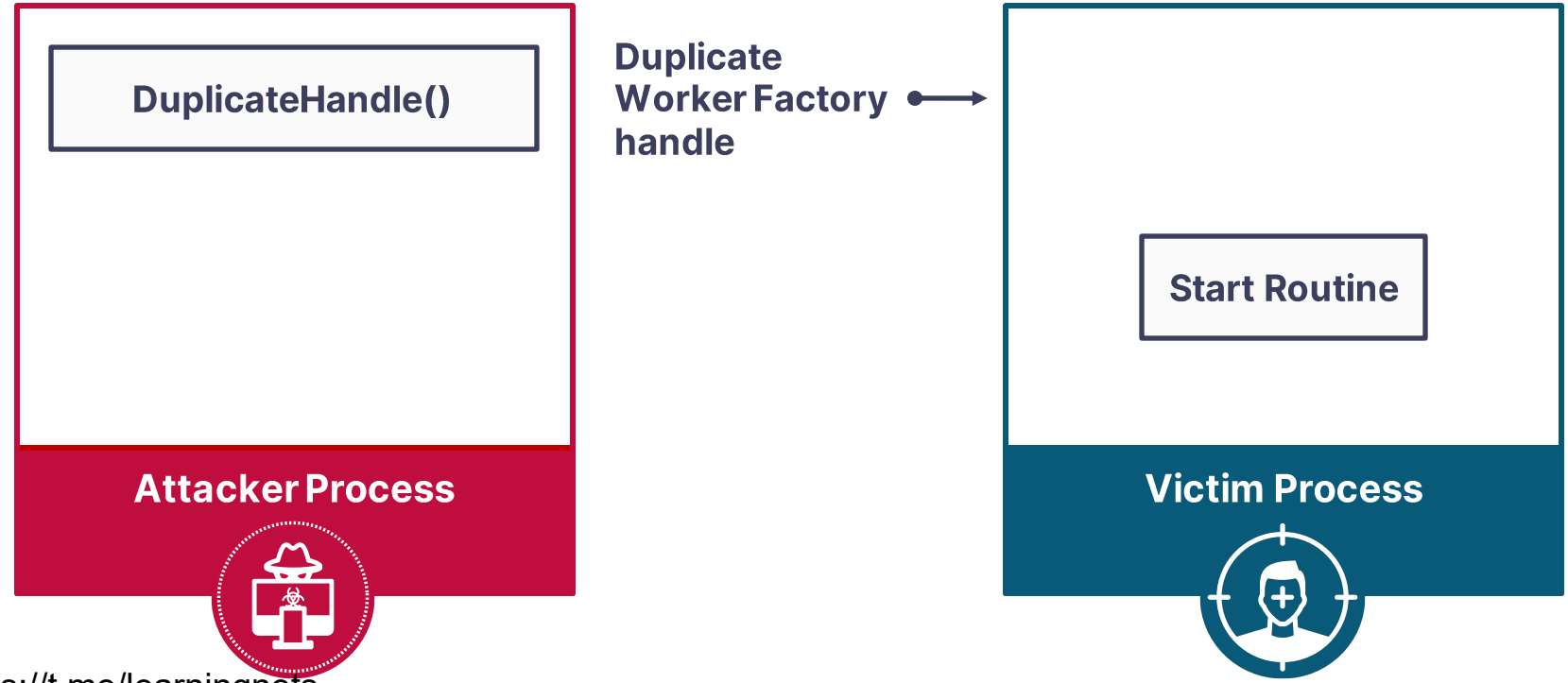

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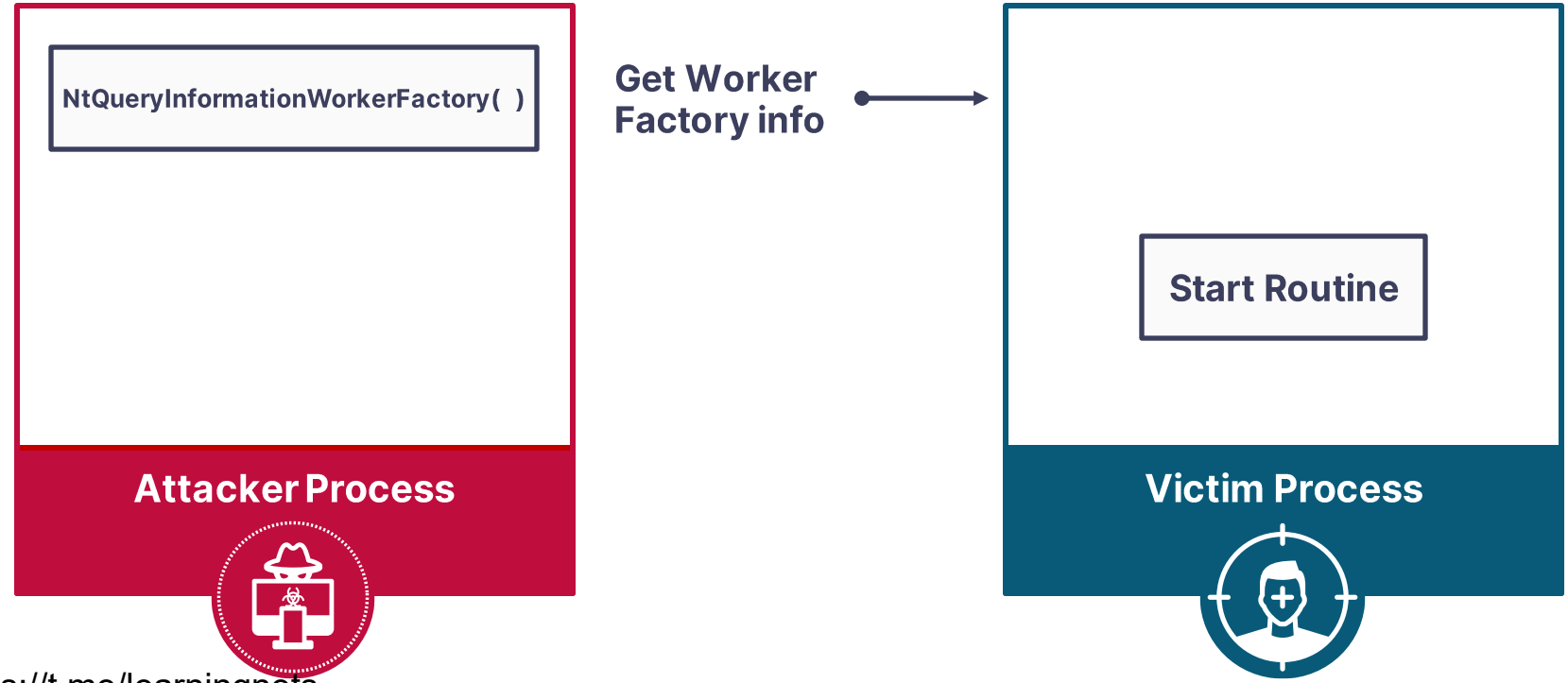

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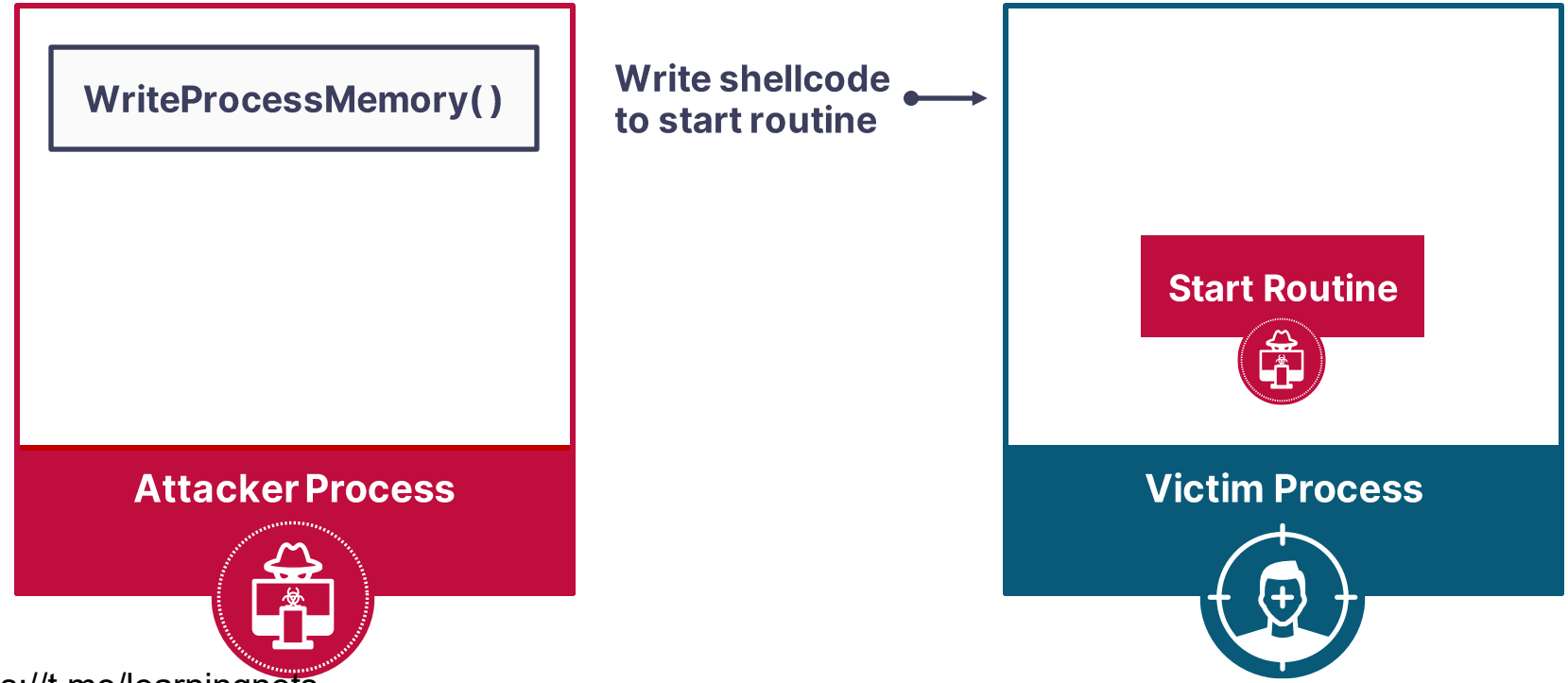

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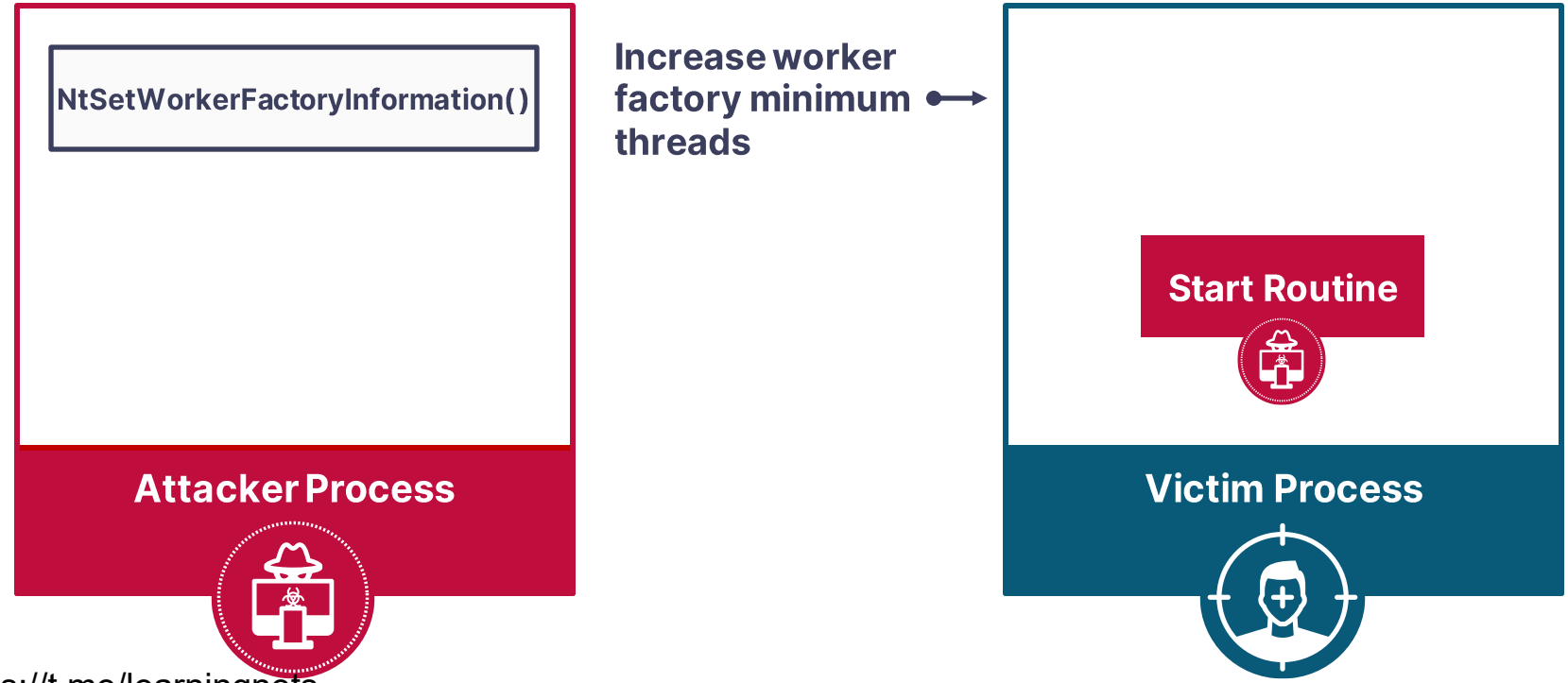


PoolParty State

# First friend in the pool

# Attacking Thread Pools

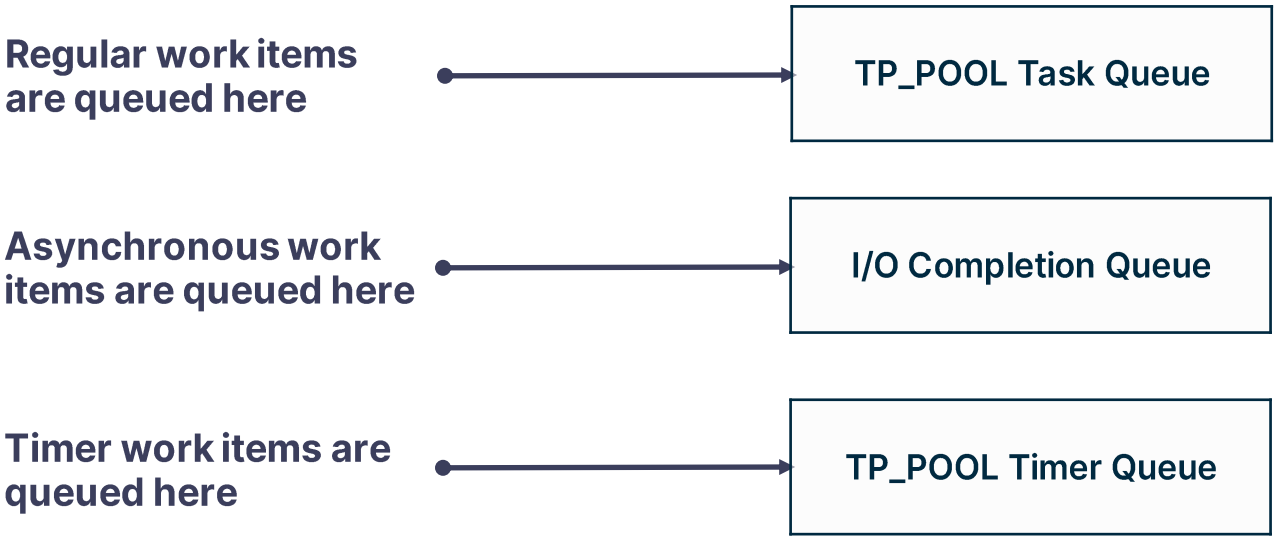
# Why Thread Pool?

| Goal | Focus of analysis | Assumptions |
| --- | --- | --- |
| Insert work items to a target process | How work items are inserted thread pools | Access to the worker factory of the thread pool |

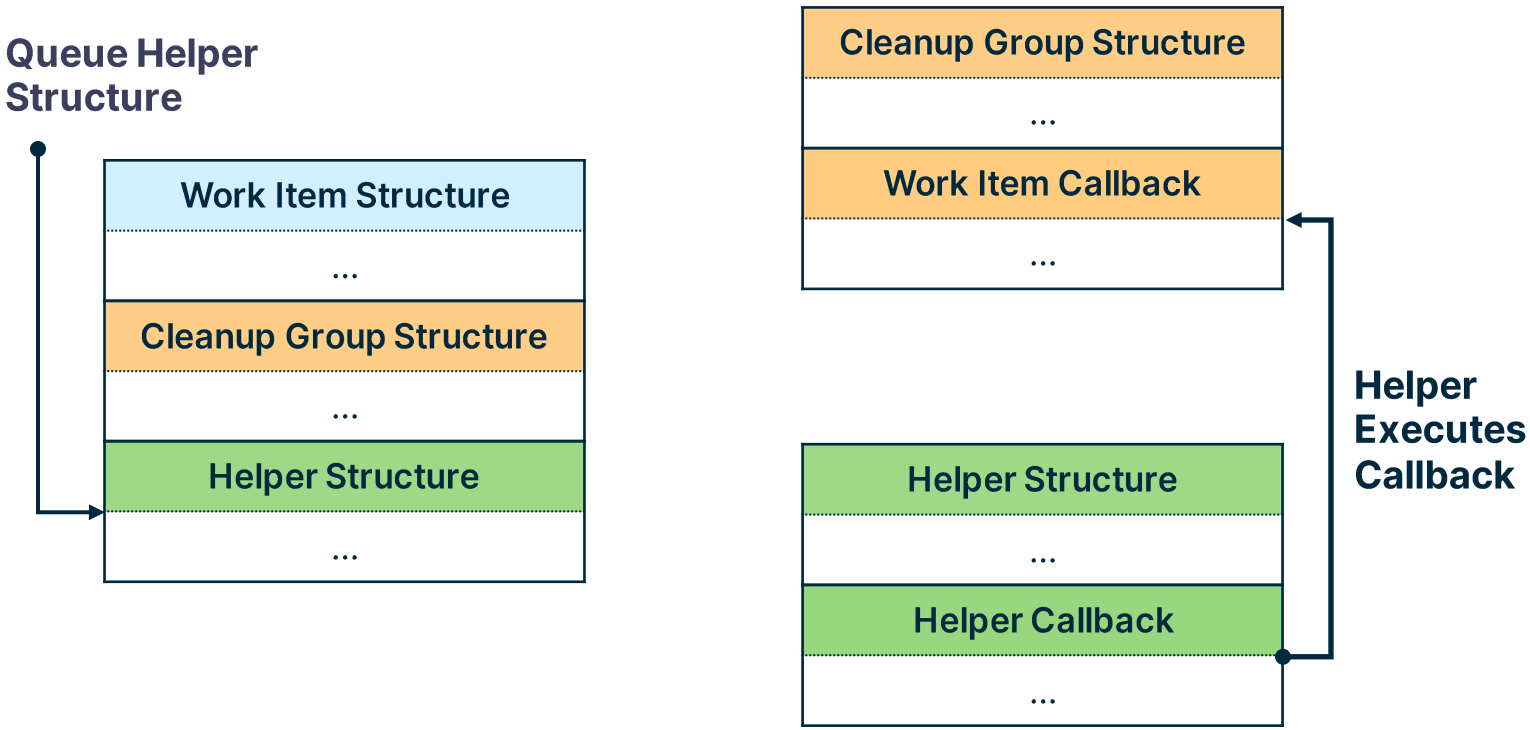
# Attacking Thread Pools - Work Item Types

| Regular Work Items | Asynchronous Work Items | Timer Work Items |
| --- | --- | --- |
| **TP_WORK** | **TP_IO** | **TP_TIMER** |
| | **TP_WAIT** | |
| | **TP_JOB** | |
| | **TP_ALPC** | |

# Attacking Thread Pools - Queue Types



# User-Mode Thread Pool - Helper Structures



# Attacking Thread Pools

| Regular Work Items | Asynchronous Work Items | Timer Work Items |
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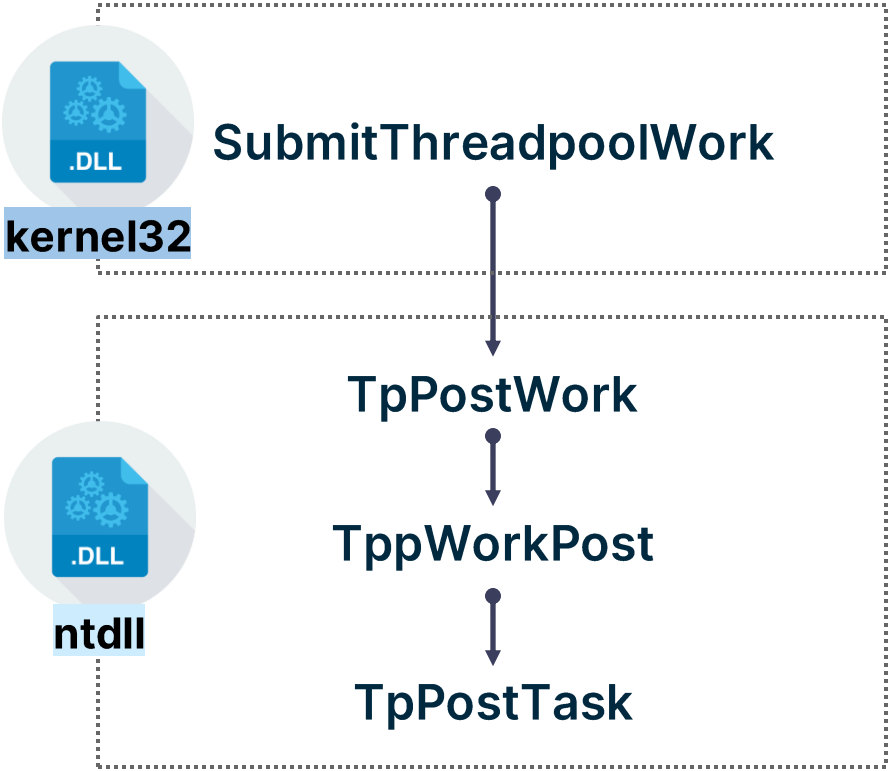
| **TP_WORK** | **TP_IO** | **TP_TIMER** |
| | **TP_WAIT** | |
| | **TP_JOB** | |
| | **TP_ALPC** | |

# Attacking Thread Pools - TP_WORK

```
typedef struct _TP_WORK
{
    _TPP_CLEANUP_GROUP_MEMBER CleanupGroupMember;
    TP_TASK Task;
    TPP_WORK_STATE WorkState;
    INT32 __PADDING__[1];
} TP_WORK, * PTP_WORK;
```

# Attacking Thread Pools - TP_WORK



# Attacking Thread Pools - TP_WORK

## **Ntdll::** TpPostTask

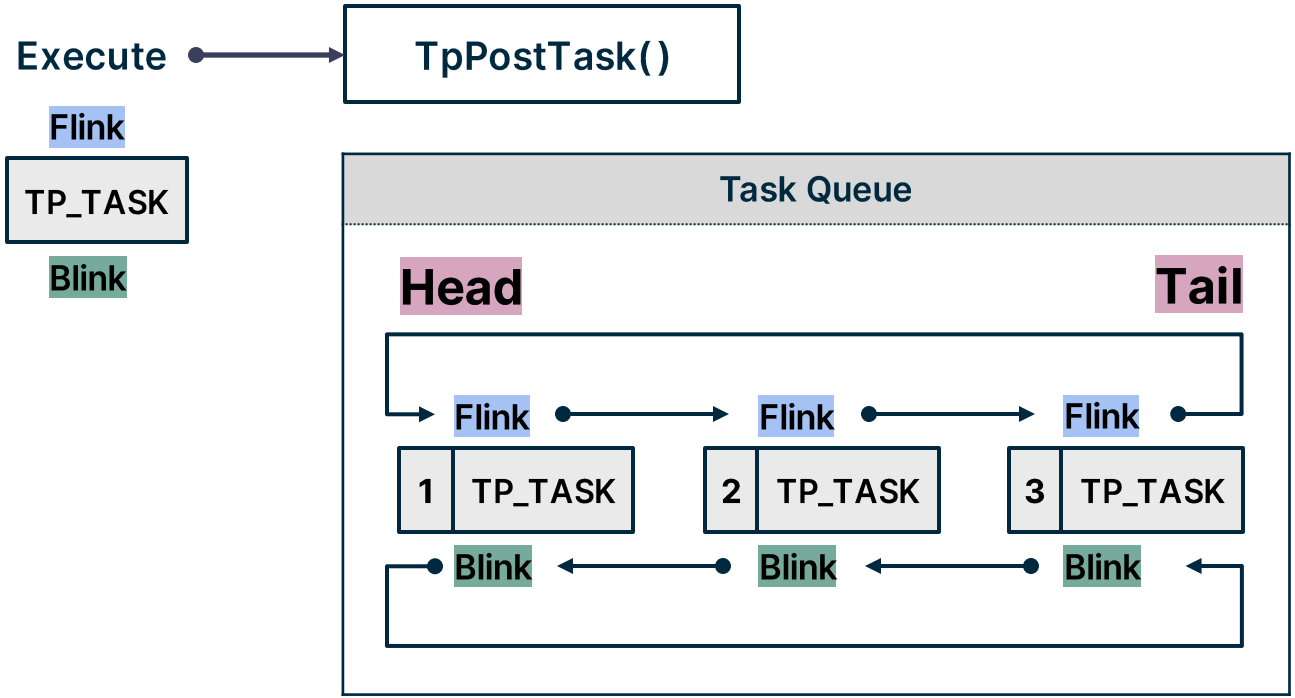
```
NTSTATUS NTAPI TpPostTask(TP_TASK* TpTask, TP_POOL* TpPool, int CallbackPriority, …)
{
    [snip]

    TPP_QUEUE* TaskQueue = &TpPool->TaskQueue[CallbackPriority];

    InsertTailList(&TaskQueue->Queue, &TpTask->ListEntry);

    [snip]
}
```

# Attacking Thread Pools - TP_WORK



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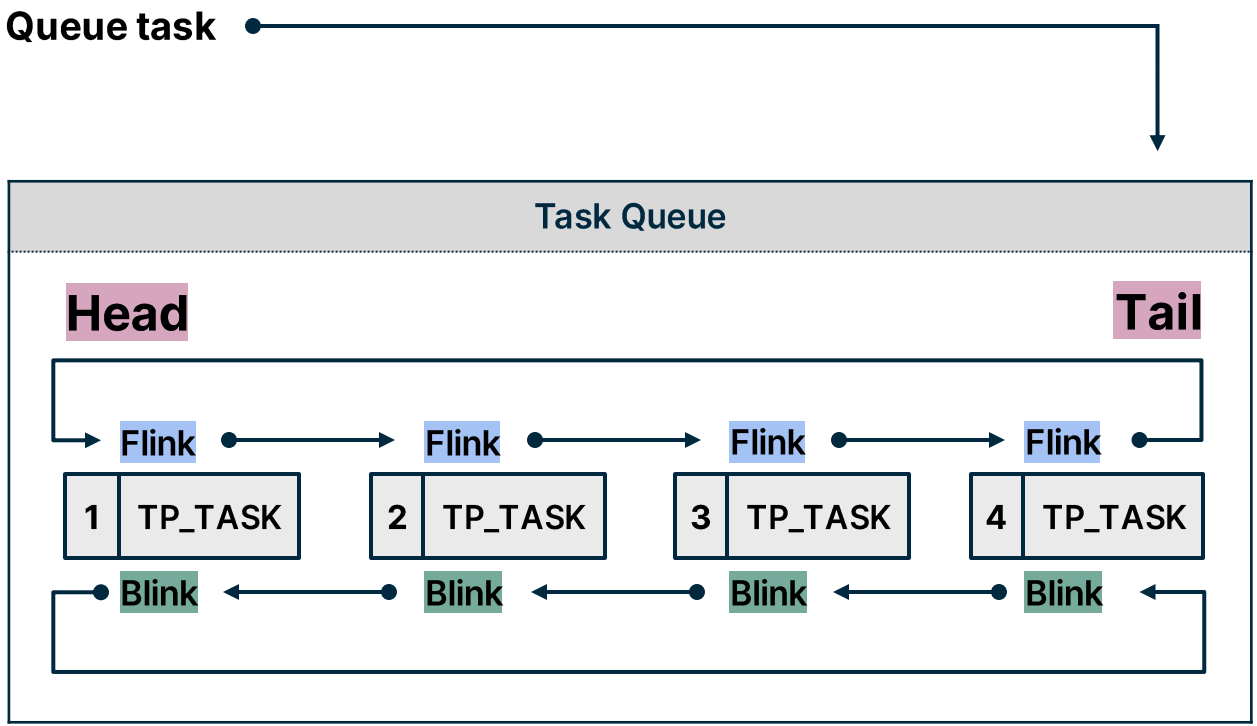

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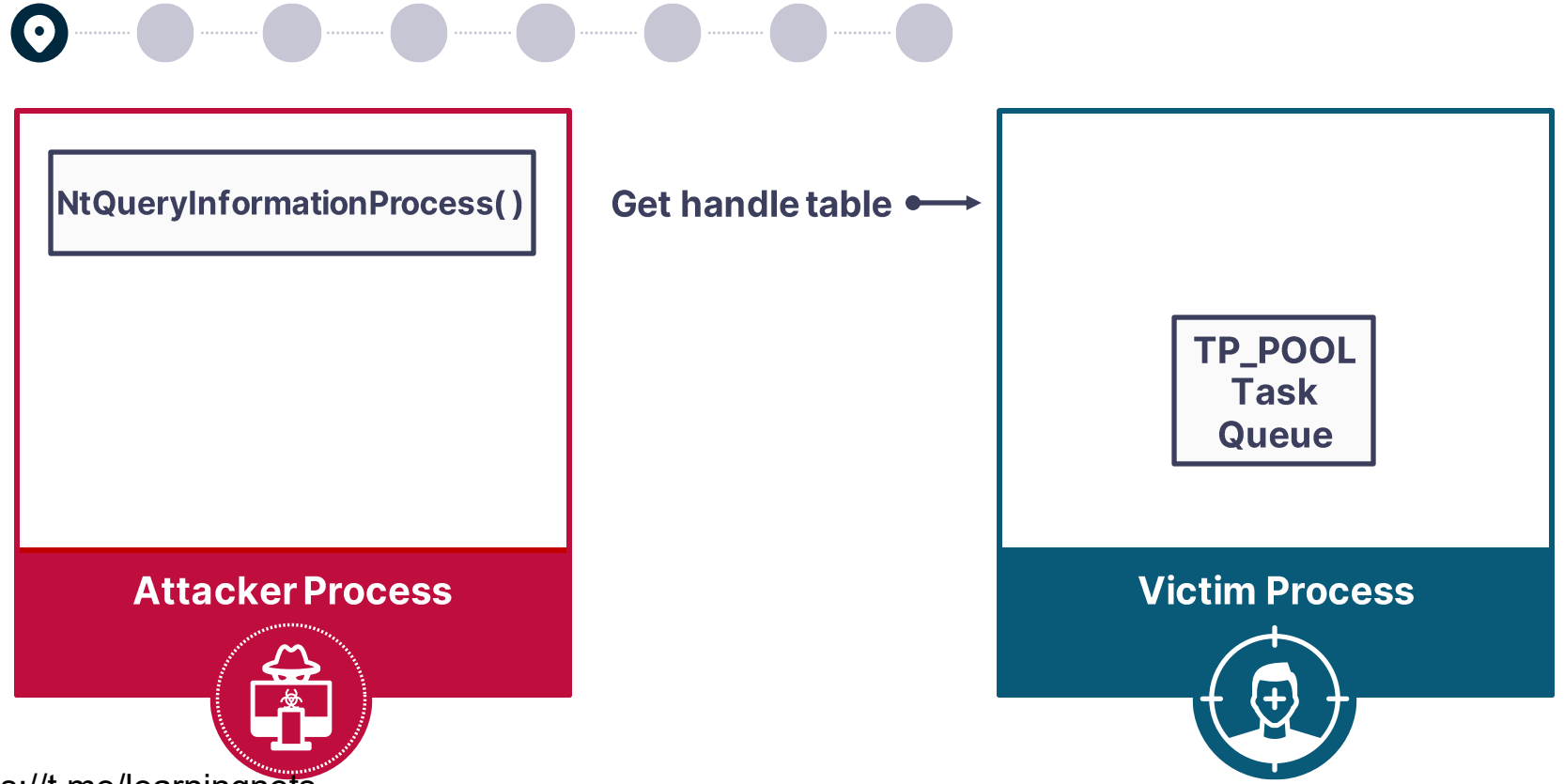

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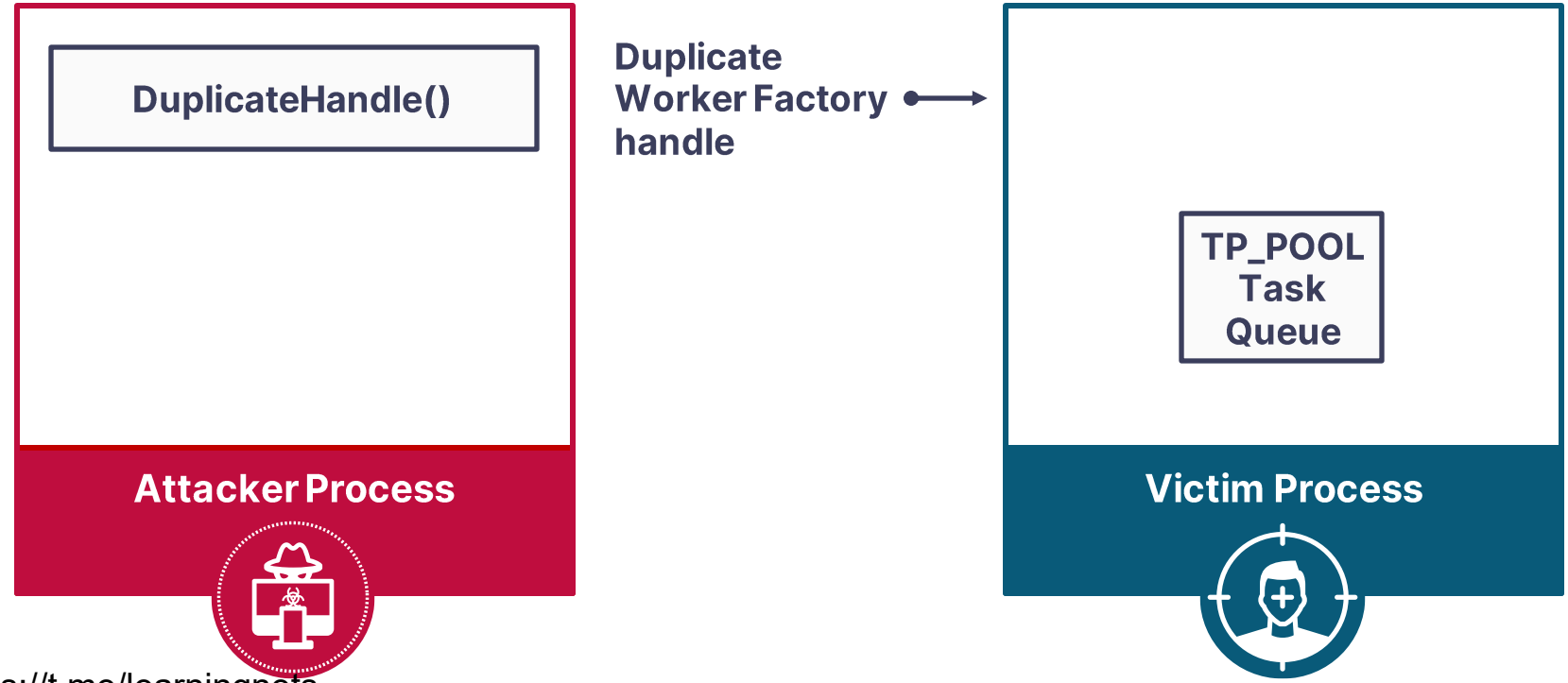

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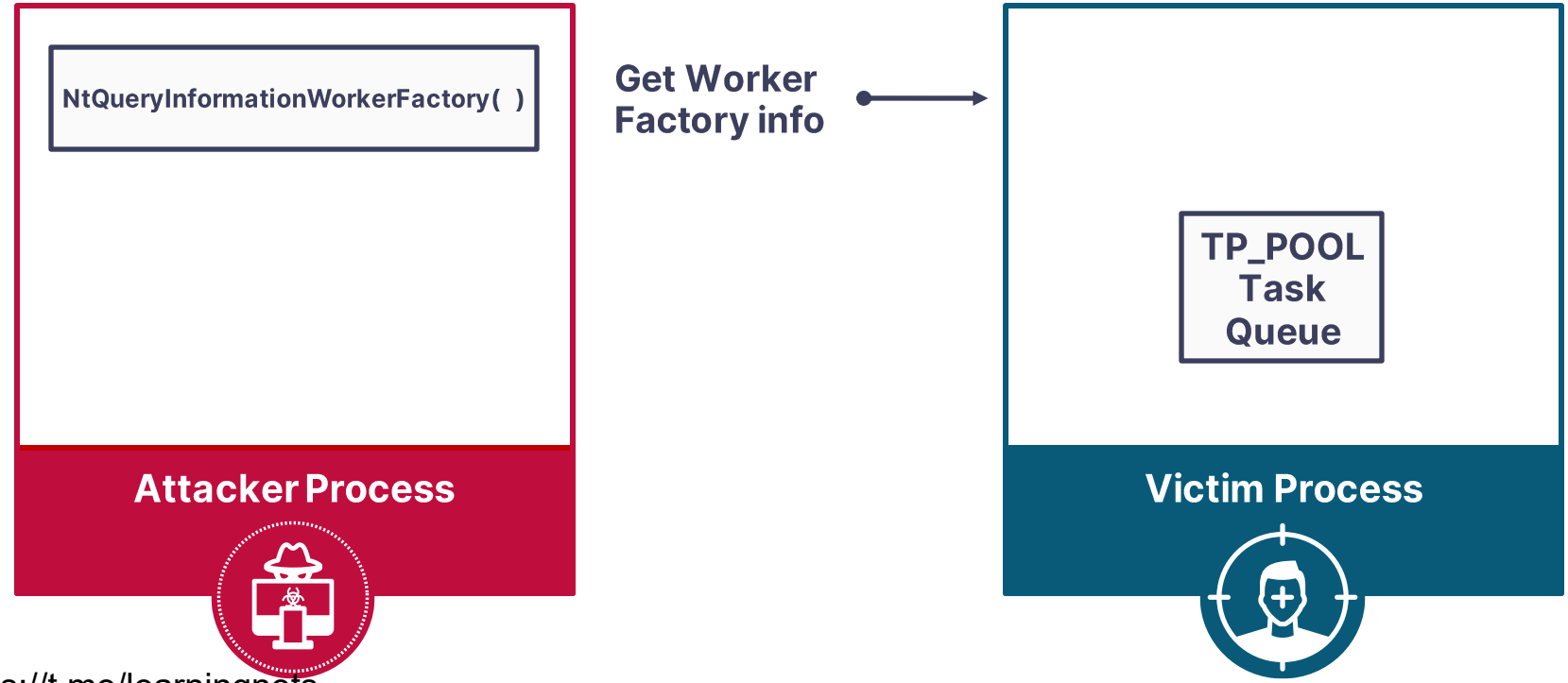

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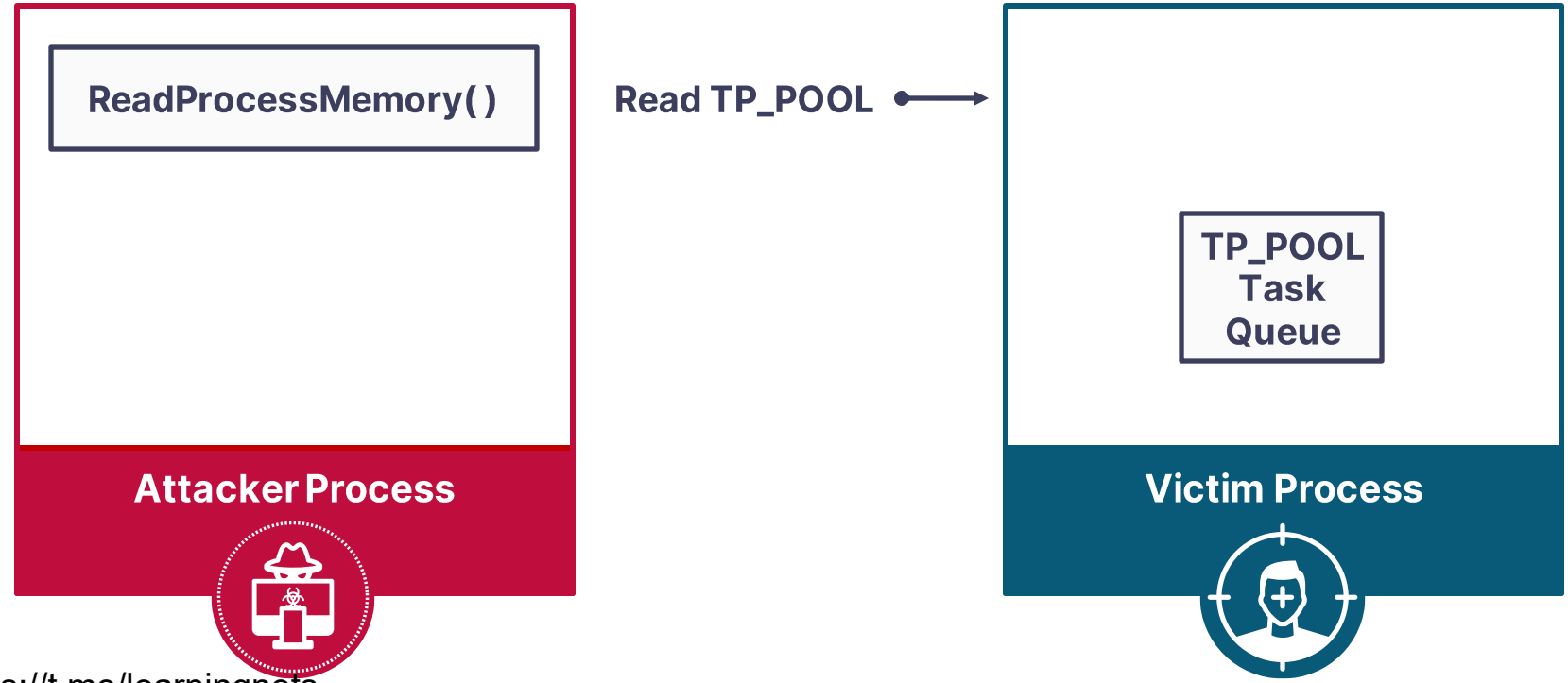

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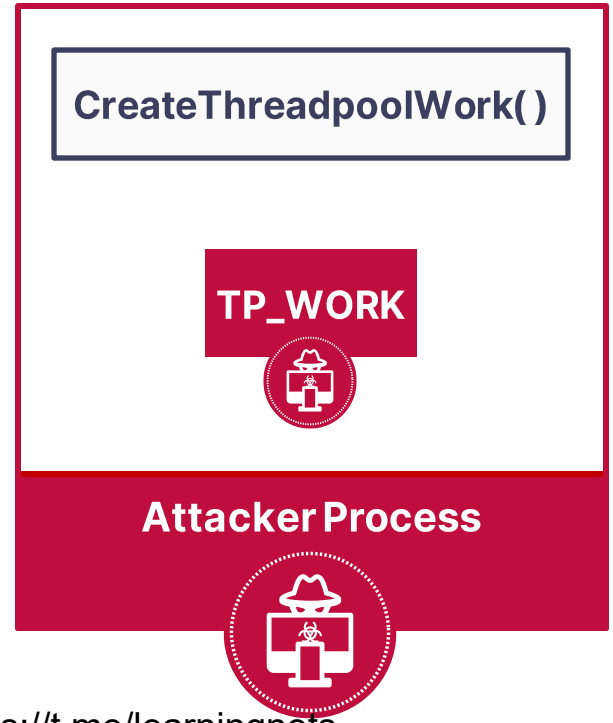


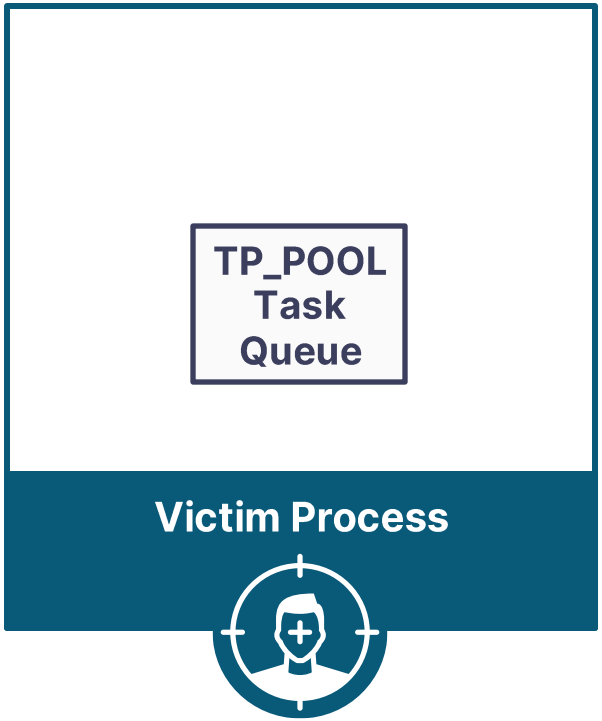

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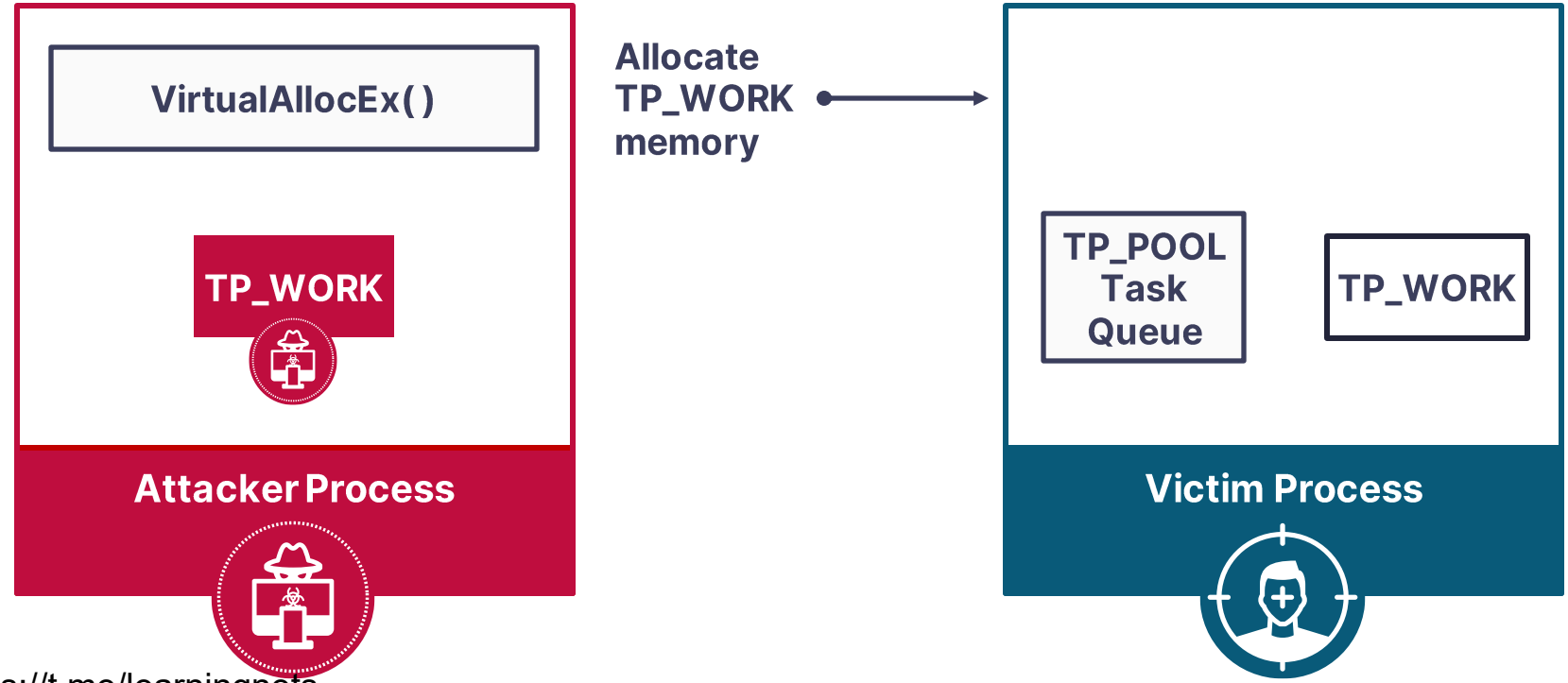

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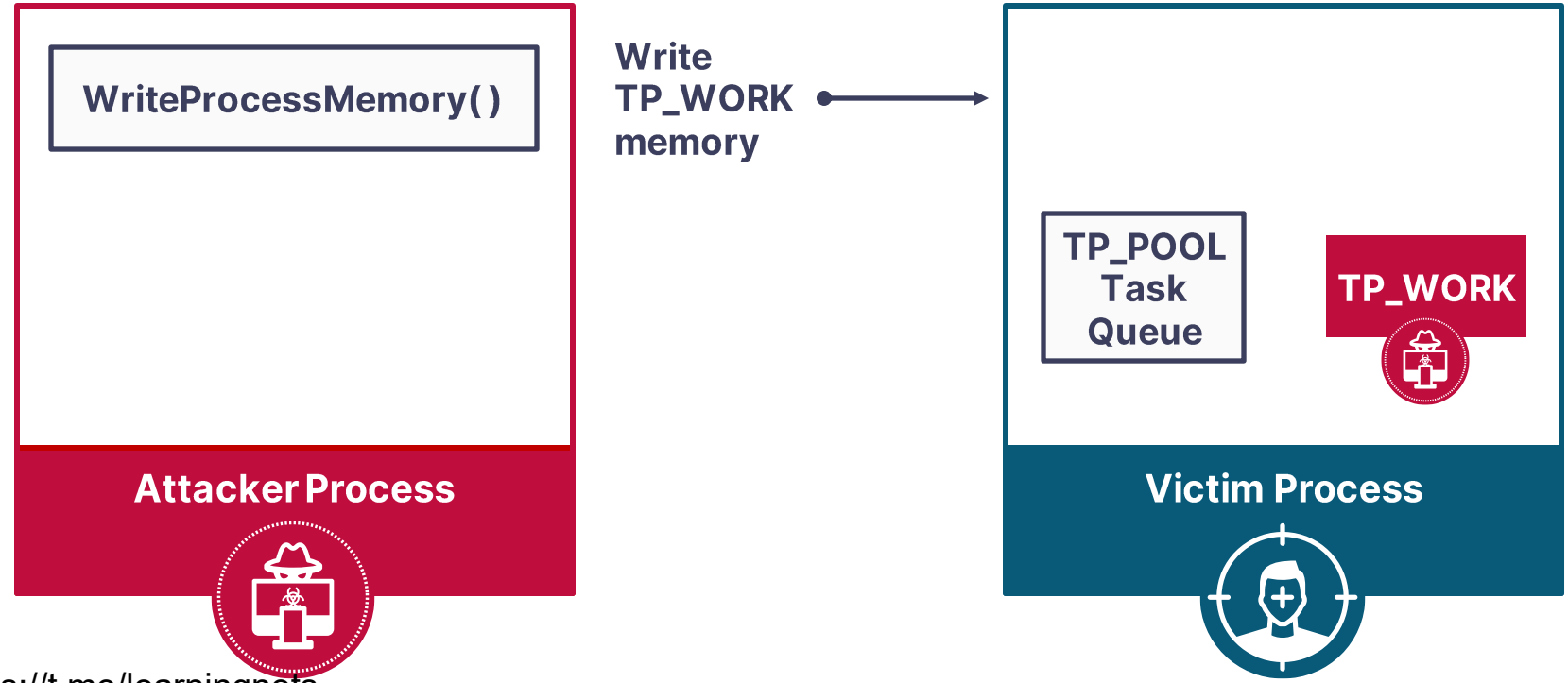

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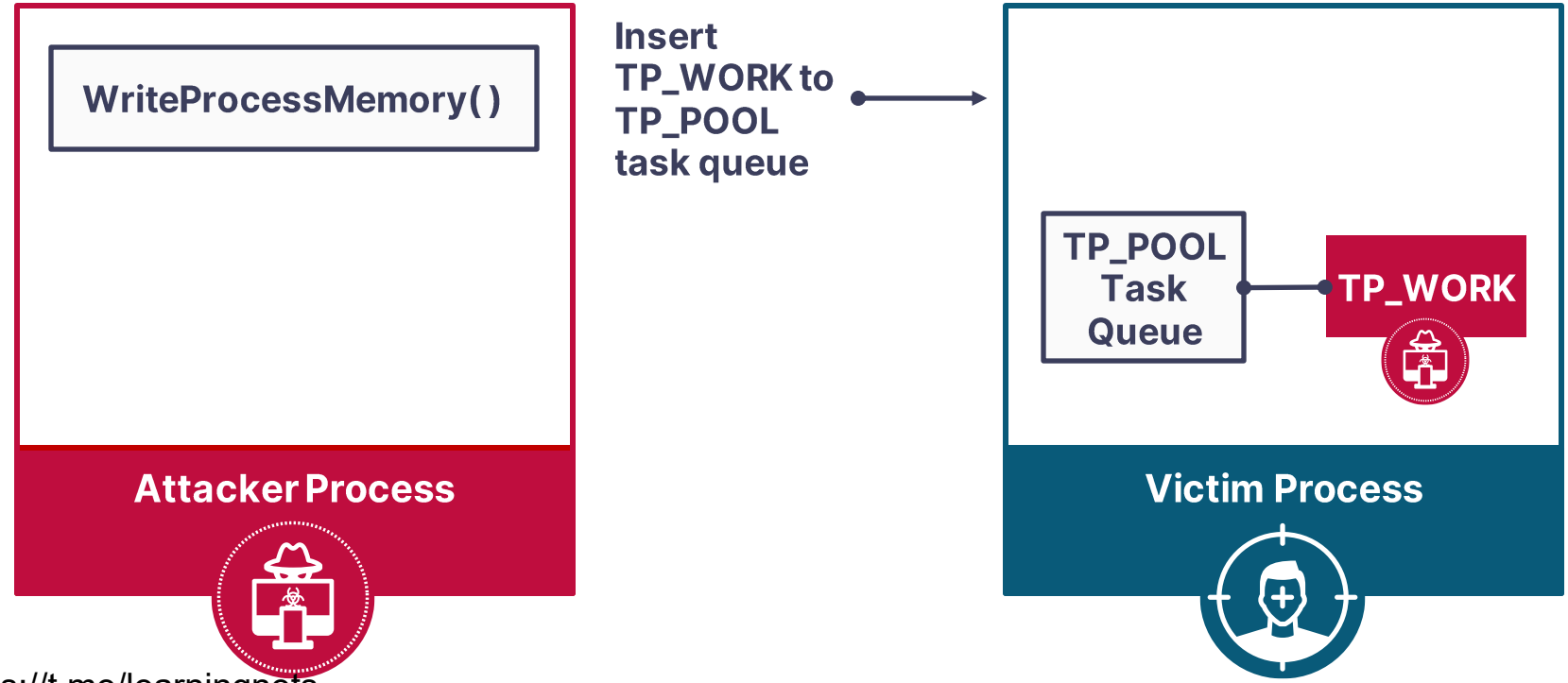


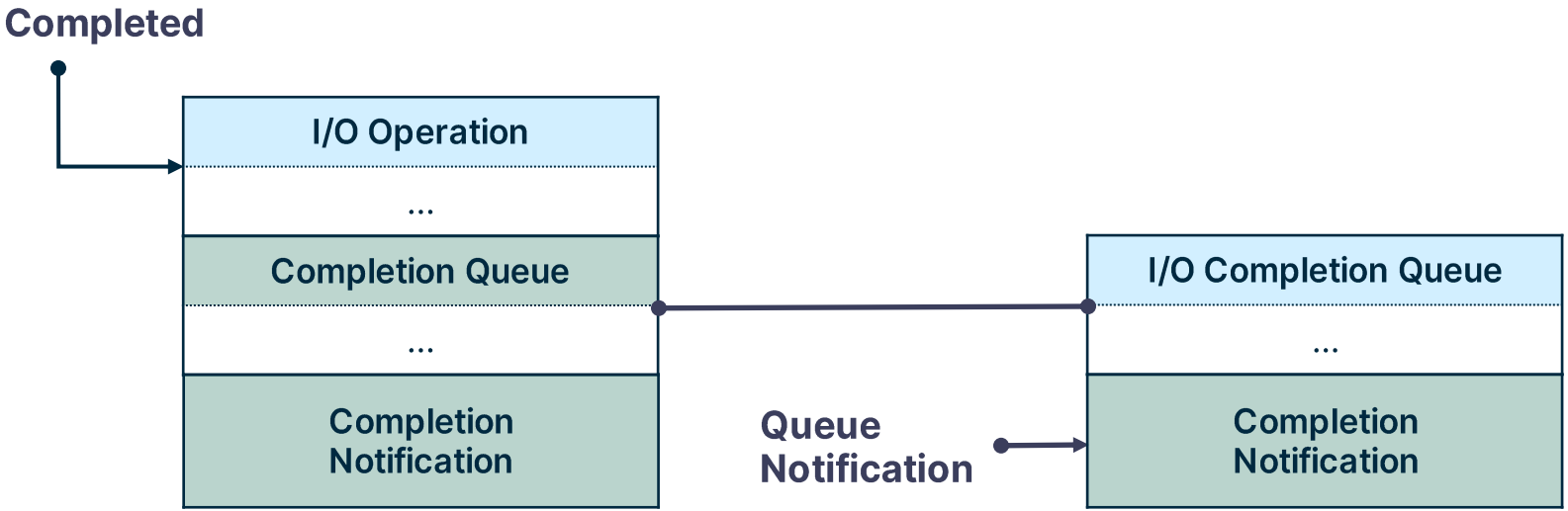
PoolParty State

# Second friend in the pool

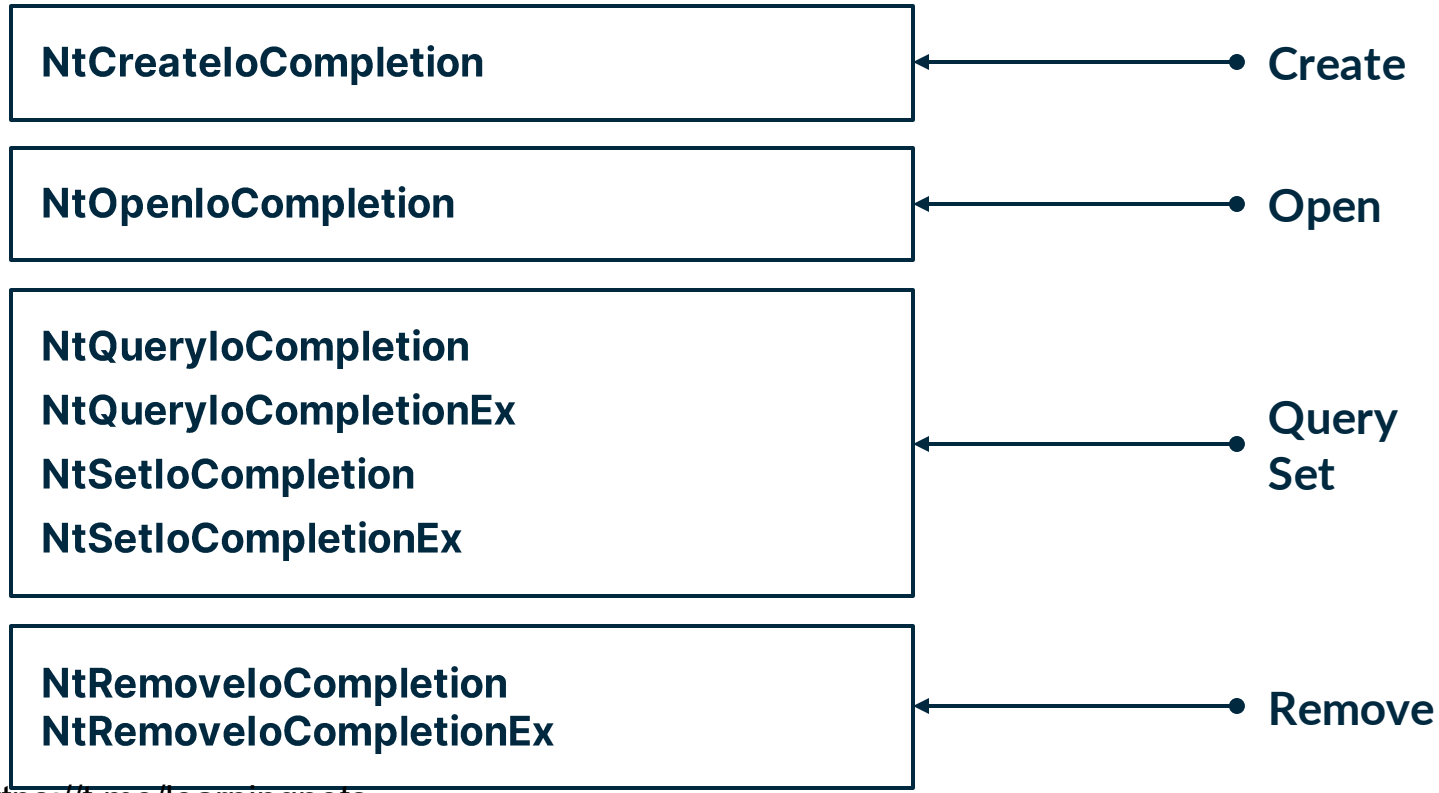
# Attacking Thread Pools

| Regular Work Items | Asynchronous Work Items | Timer Work Items |
| --- | --- | --- |
| TP_WORK | TP_IO | TP_TIMER |
| | TP_WAIT | |
| | TP_JOB | |
| | TP_ALPC | |

# I/O Completion Ports Introduction



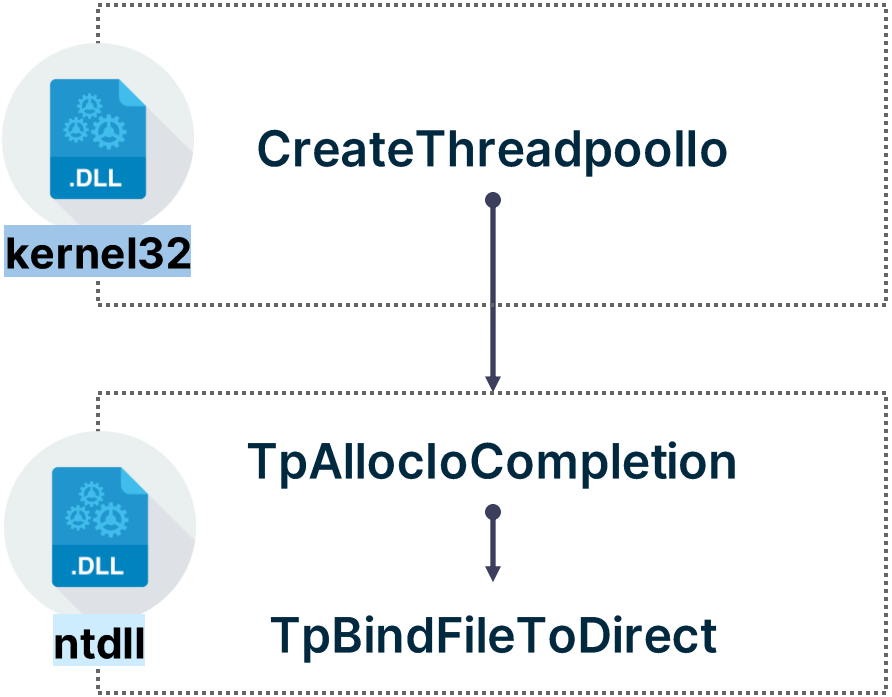
# I/O Completion Queues System Calls



# Attacking Thread Pools - TP_IO

```
typedef struct _TP_IO
{
    _TPP_CLEANUP_GROUP_MEMBER CleanupGroupMember;
    TP_DIRECT Direct;
    HANDLE File;
    INT32 PendingIrpCount;
    INT32 __PADDING__[1];
} TP_WORK, * PTP_WORK;
```

# Attacking Thread Pools - TP_IO

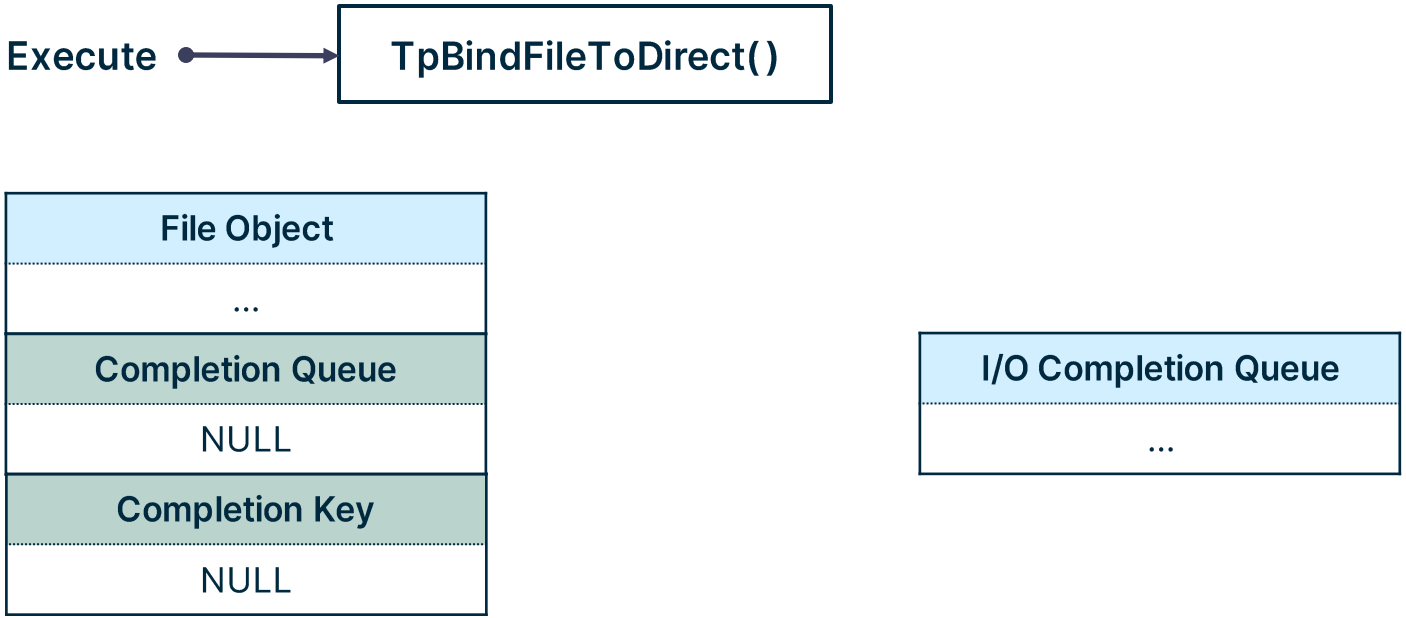


# Attacking Thread Pools - TP_IO

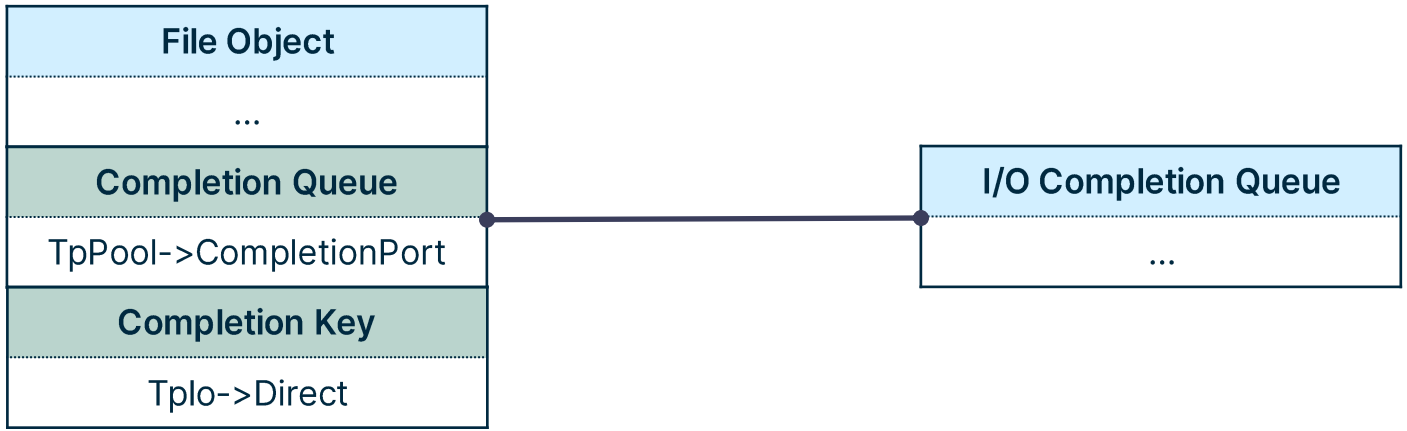
## **Ntdll::** TpBindFileToDirect

```
NTSTATUS NTAPI TpBindFileToDirect(HANDLE  hFile, TP_DIRECT* TpDirect, TP_POOL* TpPool)
{
   [snip]

   FILE_COMPLETION_INFORMATION  FileCompletionInfo{ 0 };
   FileCompletionInfo.Key  = TpDirect;
   FileCompletionInfo.Port  = TpPool->CompletionPort;

   NtSetInformationFile(
      hFile,
      &IoStatusBlock,
      &FileCompletionInfo,
      sizeof(FILE_COMPLETION_INFORMATION),
      FileCompletionInformation);

   [snip]
}
```

# Attacking Thread Pools - TP_IO



# Attacking Thread Pools - TP_IO



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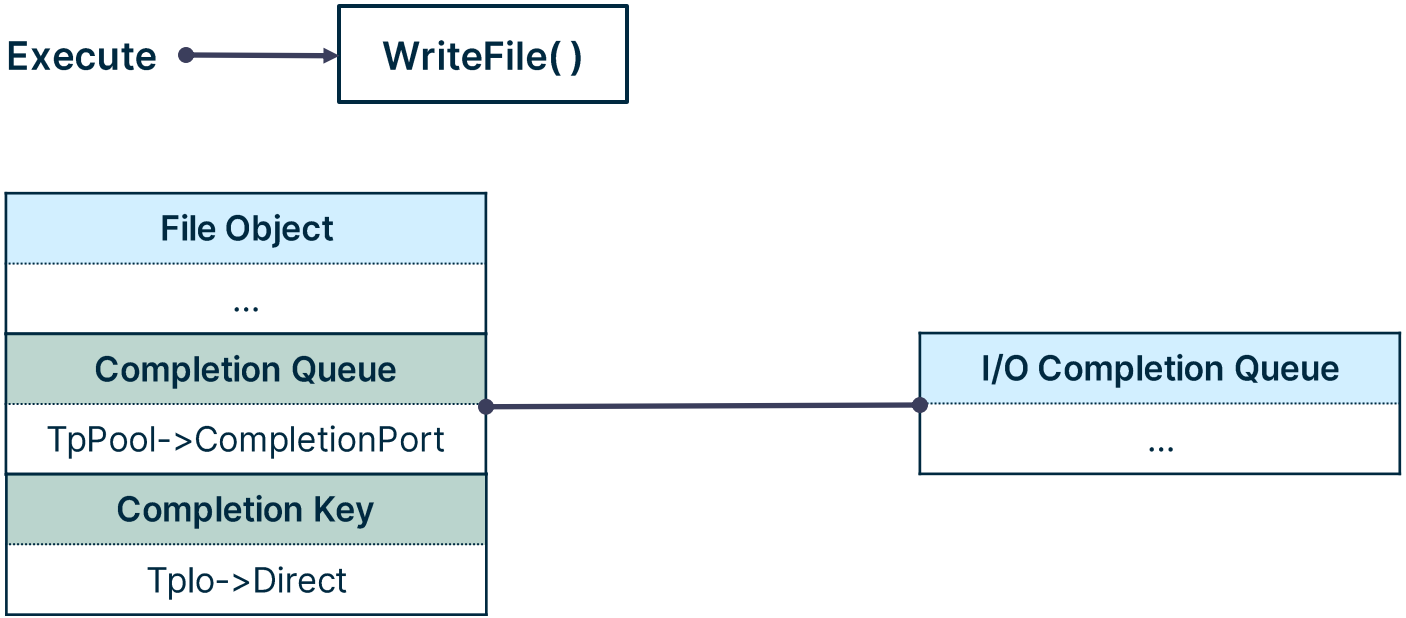

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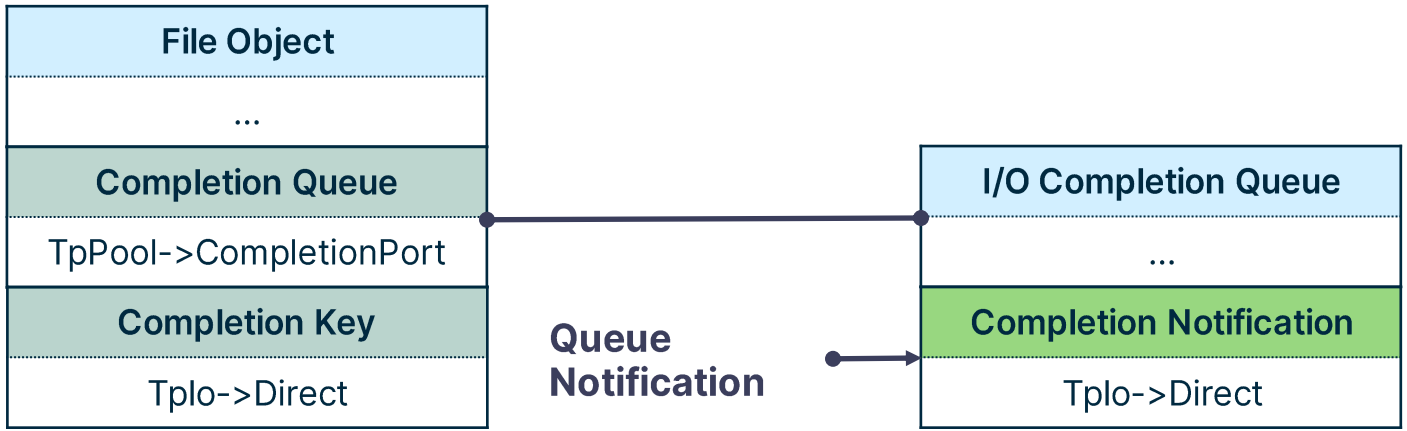

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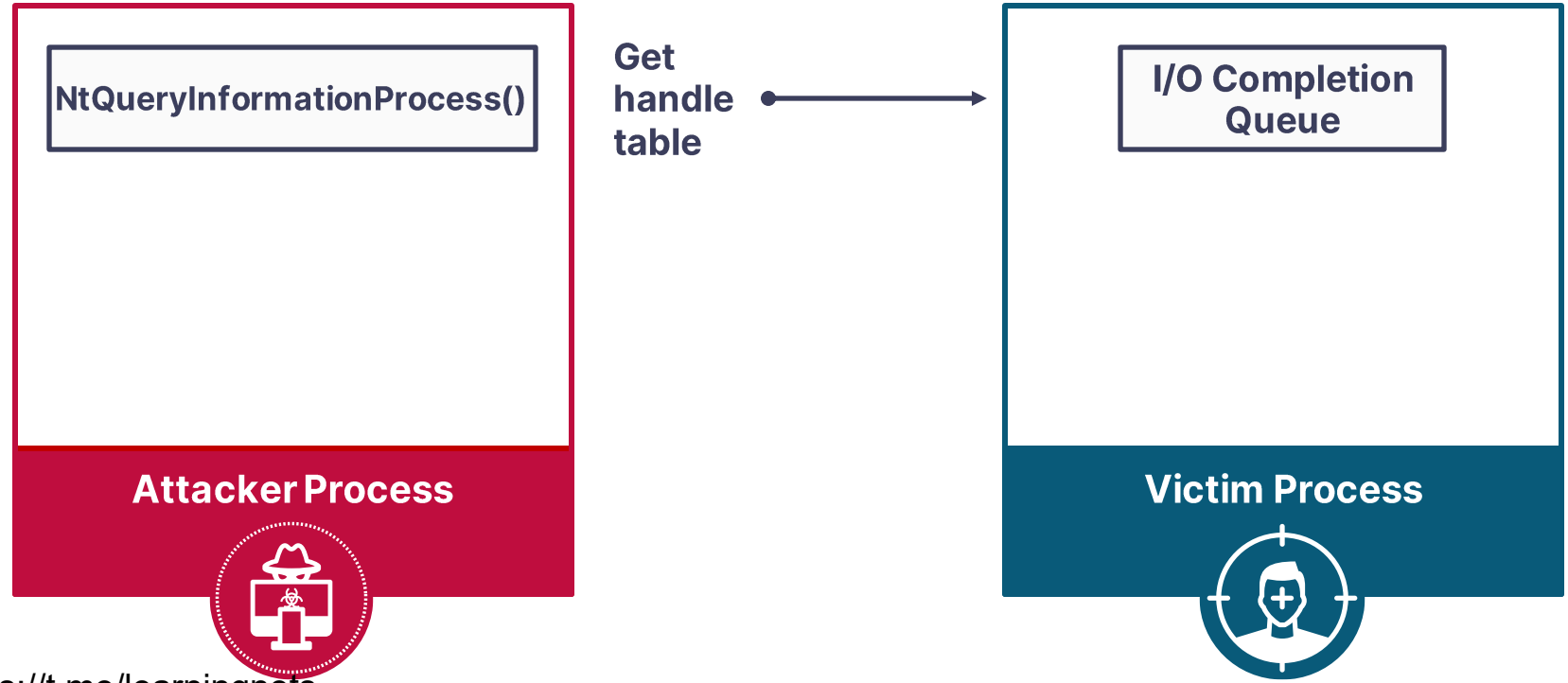

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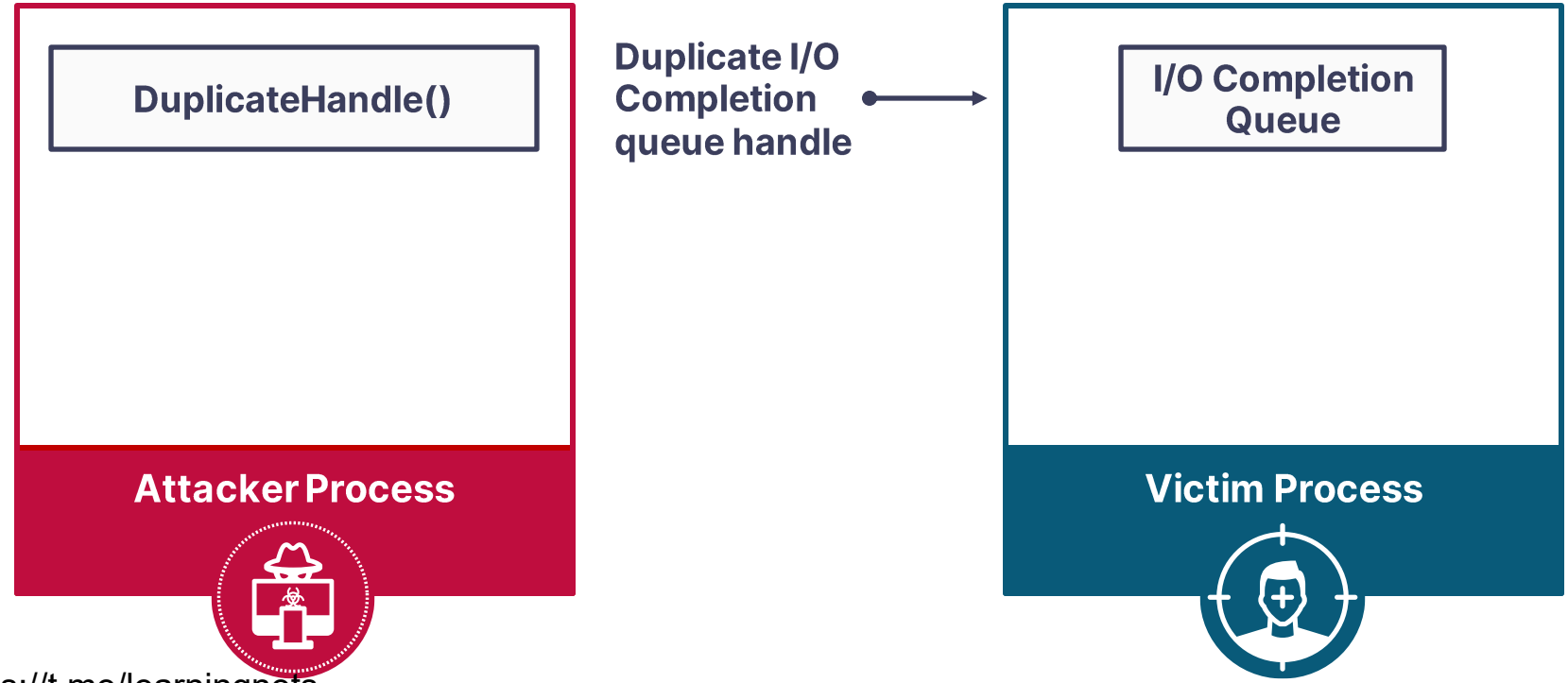
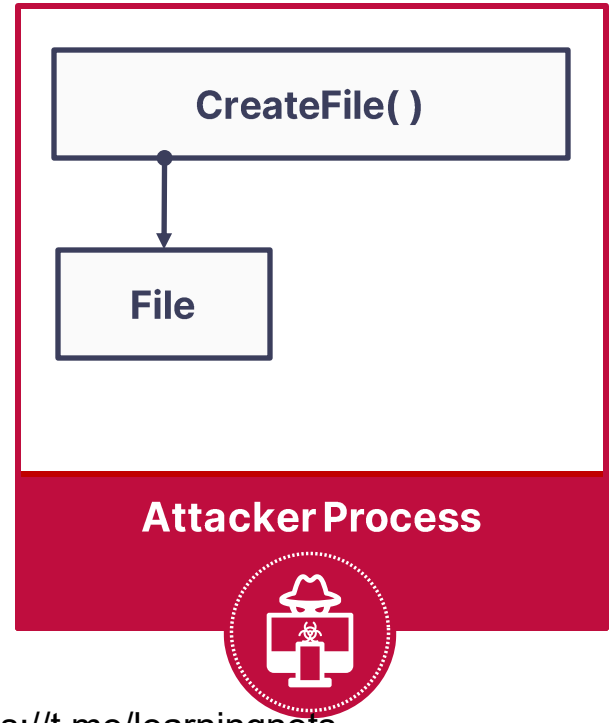
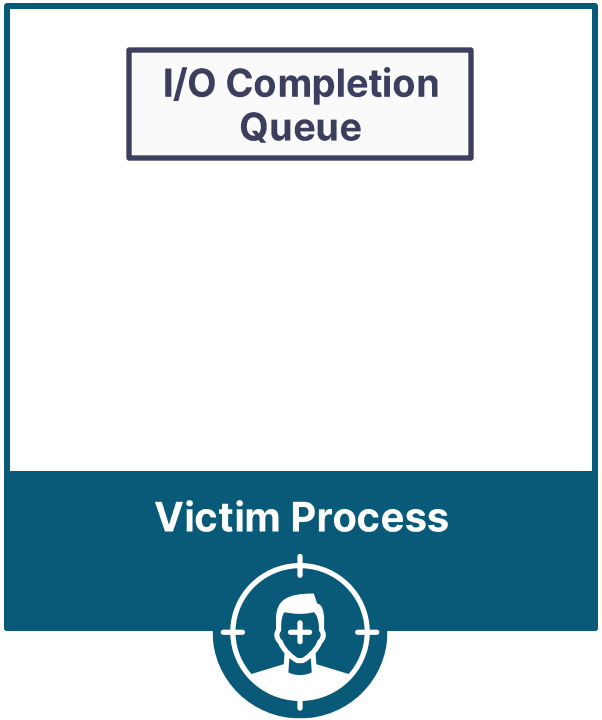
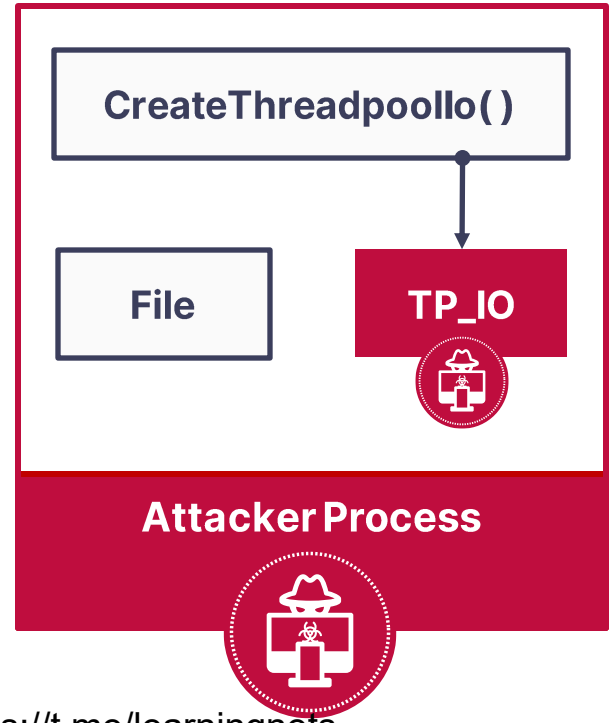


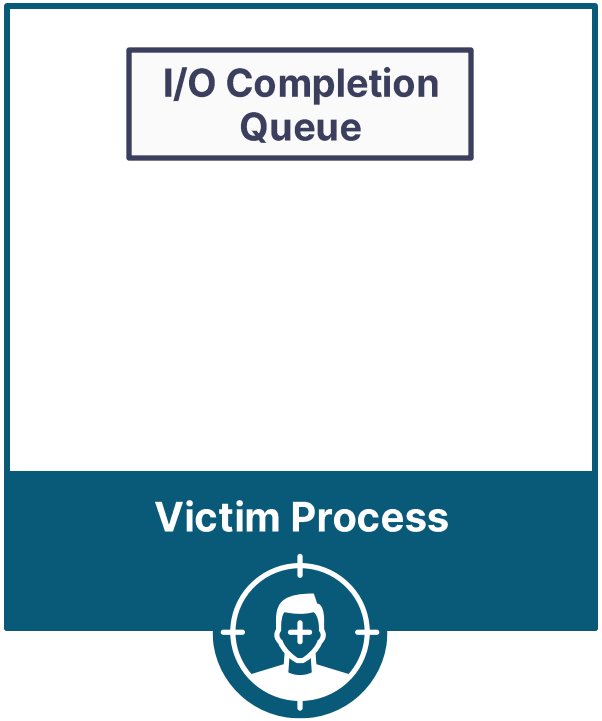
# Attacking Thread Pools - TP_IO



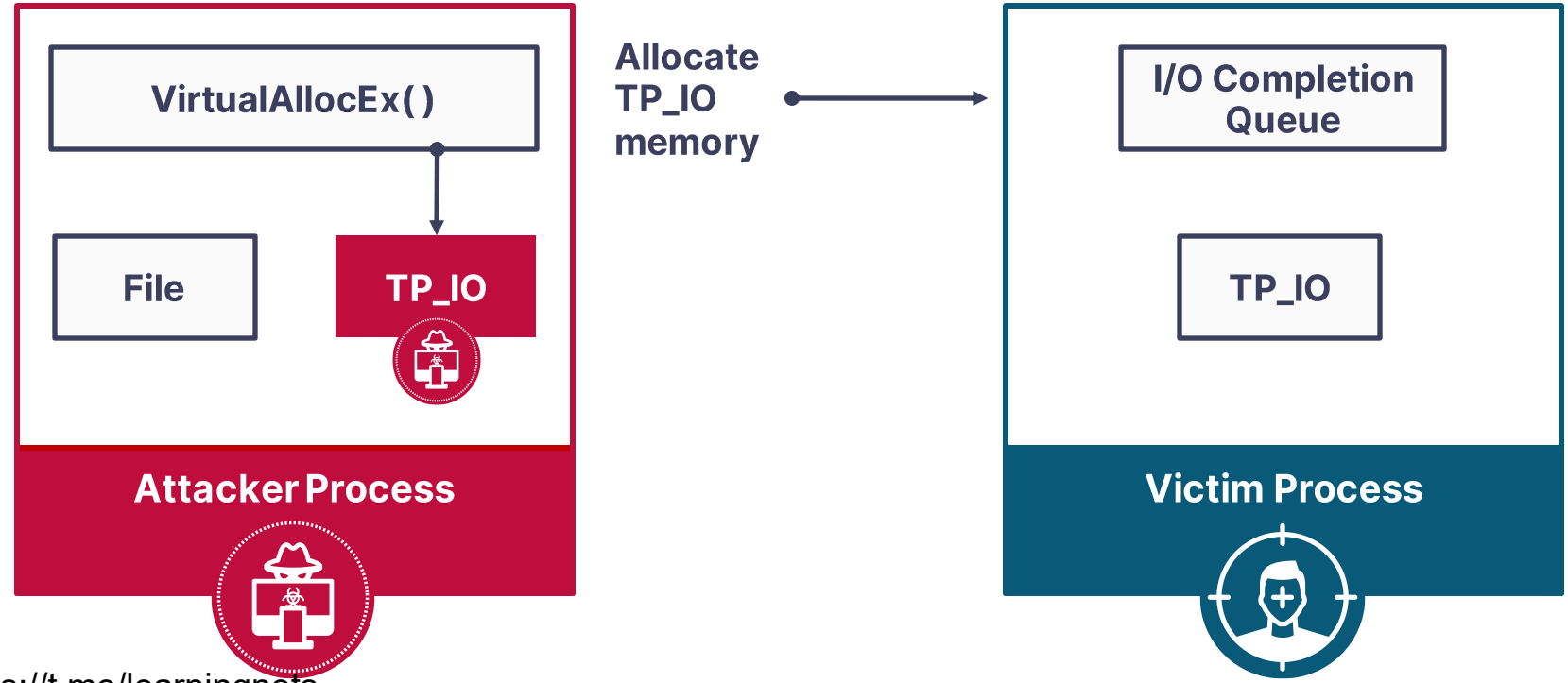



# Attacking Thread Pools - TP_IO



# Attacking Thread Pools - TP_IO



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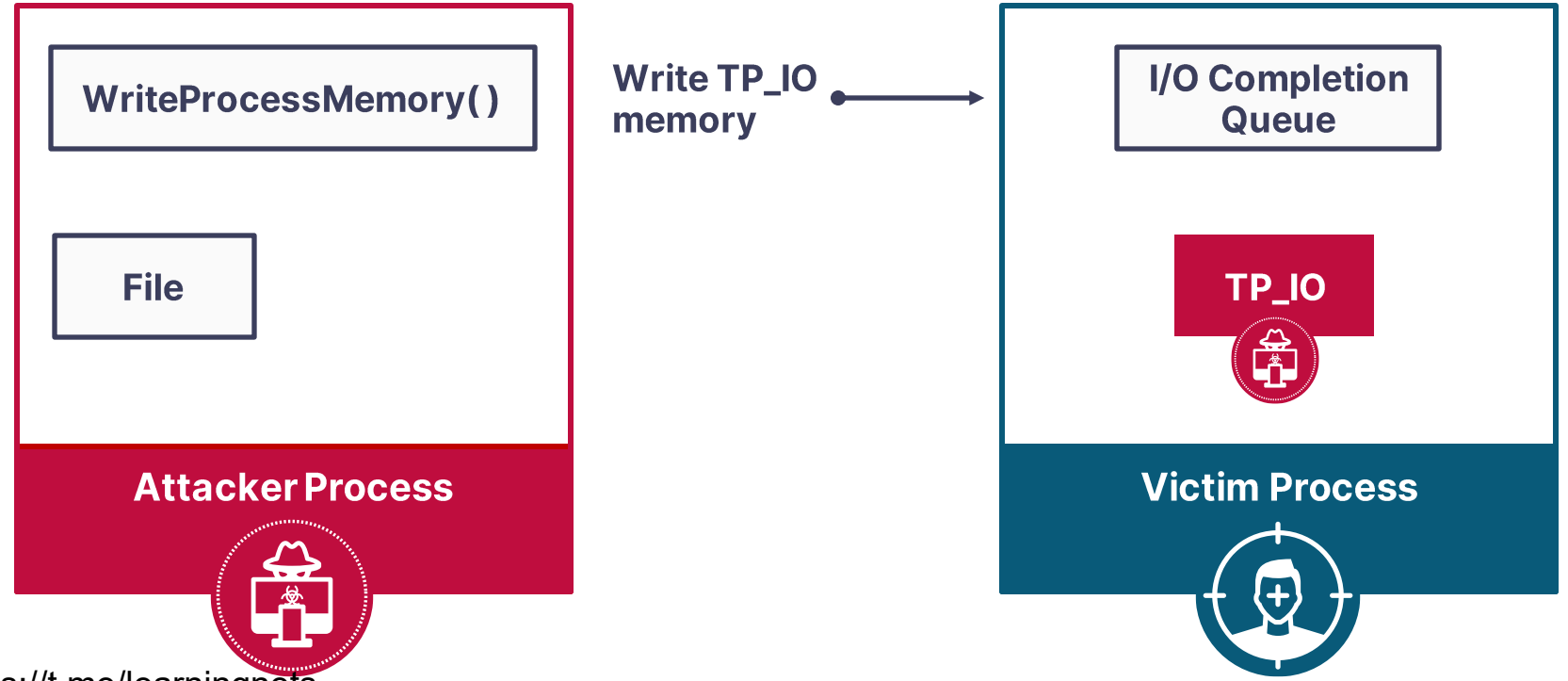

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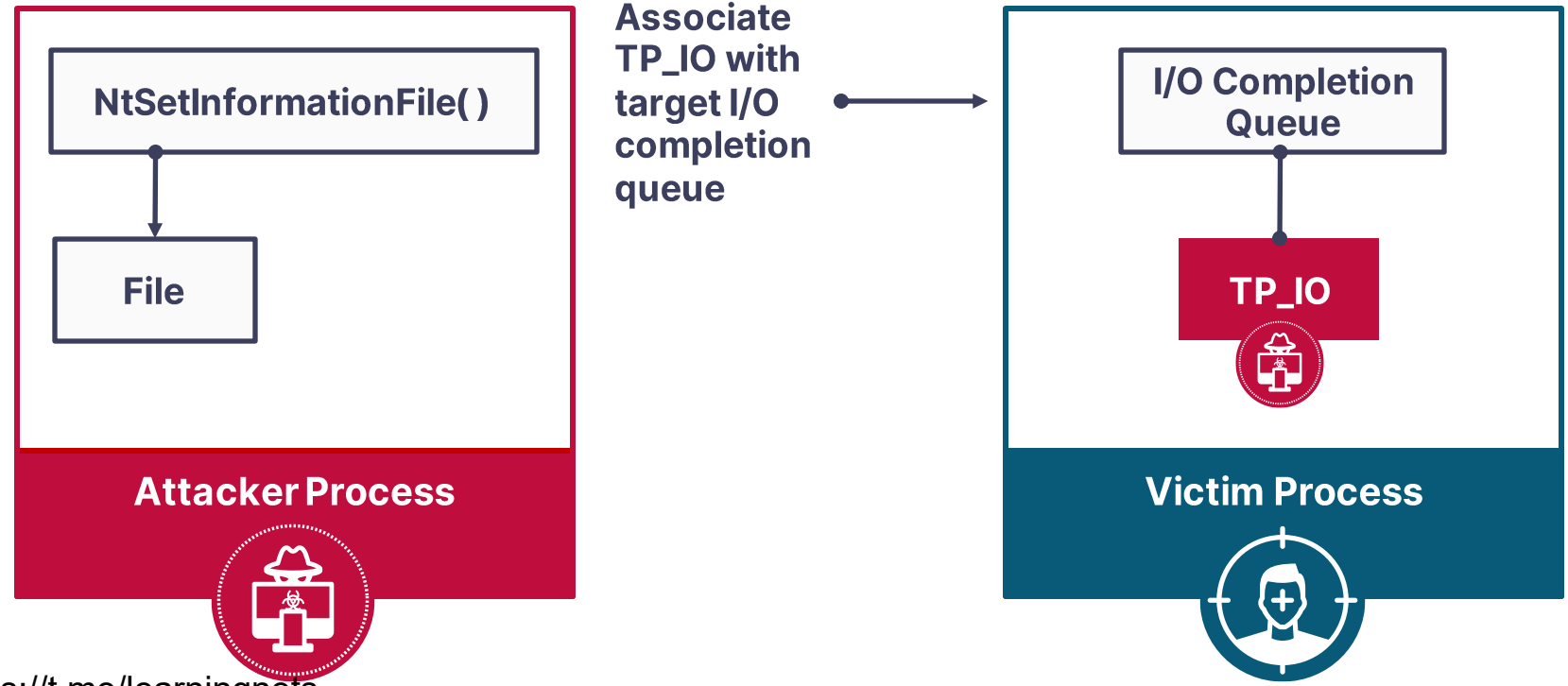
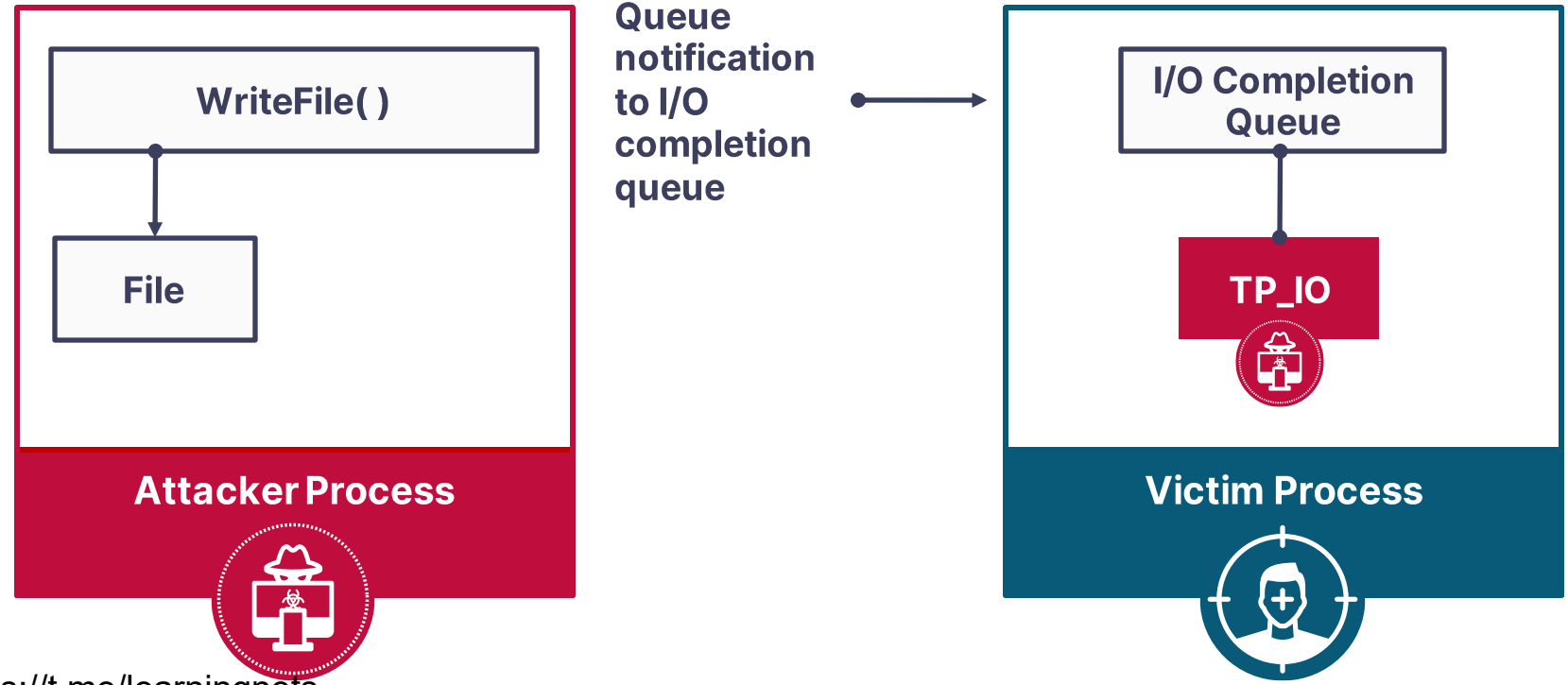


# Attacking Thread Pools - TP_IO



# Attacking Thread Pools - IO, ALPC, JOB, …

Any TP_DIRECT notification queued to I/O completion queue gets executed

Notifications can be queued by object operation completion

- File objects (TP_IO)
- ALPC port objects (TP_ALPC)
- Job objects (TP_JOB)
- Waitable objects – (TP_WAIT)

Notifications can be queued directly by NtSetIoCompletion system call

PoolParty State

# Five new friends in the pool

# Attacking Thread Pools

| Regular Work Items | Asynchronous Work Items | Timer Work Items |
| --- | --- | --- |
| TP_WORK | TP_IO | TP_TIMER |
| | TP_WAIT | |
| | TP_JOB | |
| | TP_ALPC | |

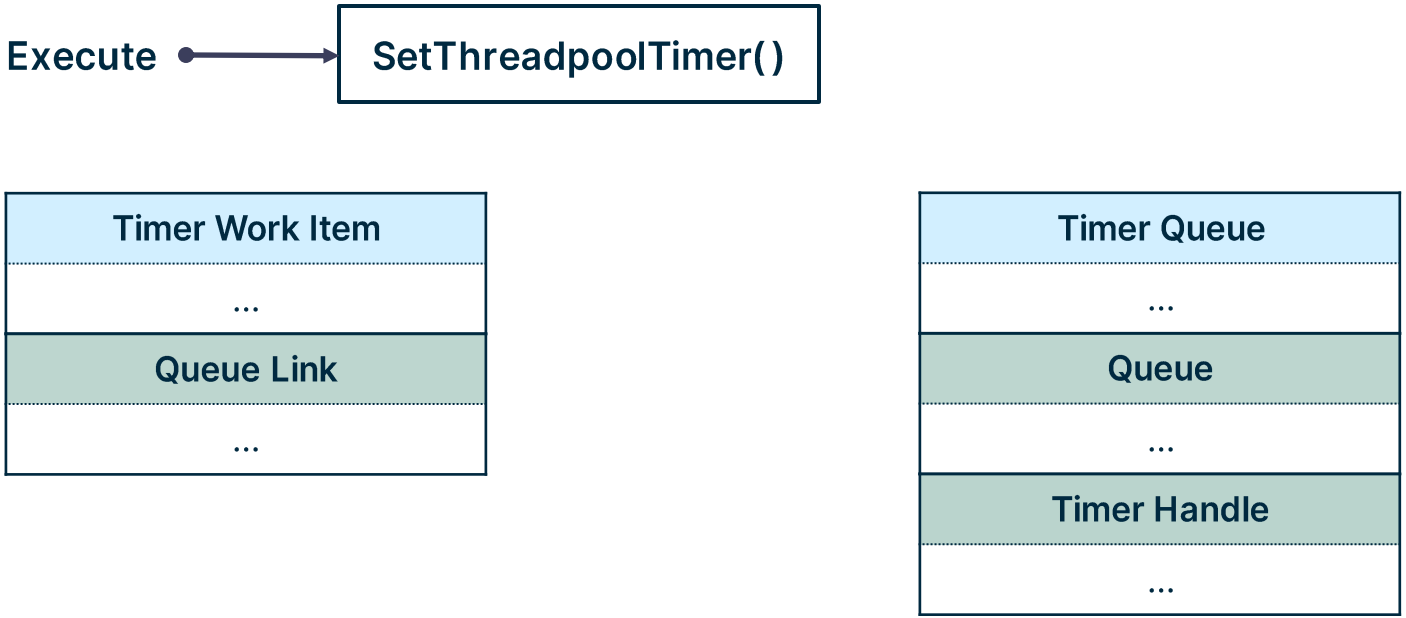
# Attacking Thread Pools - TP_TIMER

**No timer handle is supplied**

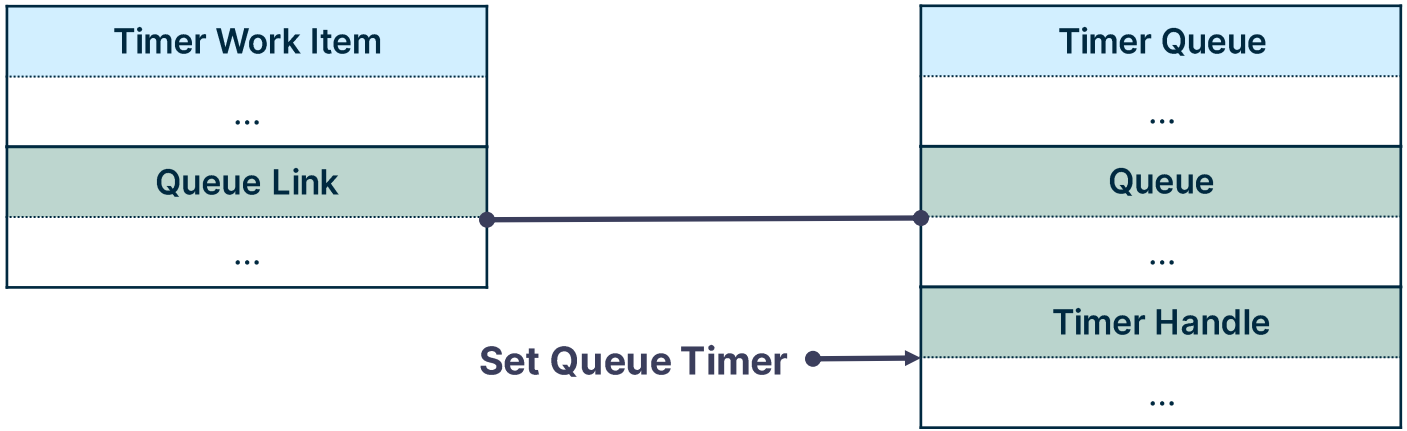
```
PTP_TIMER NTAPI CreateThreadpoolTimer(
    _In_     PTP_TIMER_CALLBACK TimerCallback,
    _In_Opt  PVOID TimerContext,
    _In_Opt  PTP_CALLBACK_ENVIRON TpCallbackEnviron
);
```

```
void NTAPI SetThreadpoolTimer(
    _In_     PTP_TIMER_CALLBACK TimerCallback,
    _In_Opt  PFILETIME DueTime,
    _In_     DWORD Period,
    _In_     DWORD WindowLength
);
```

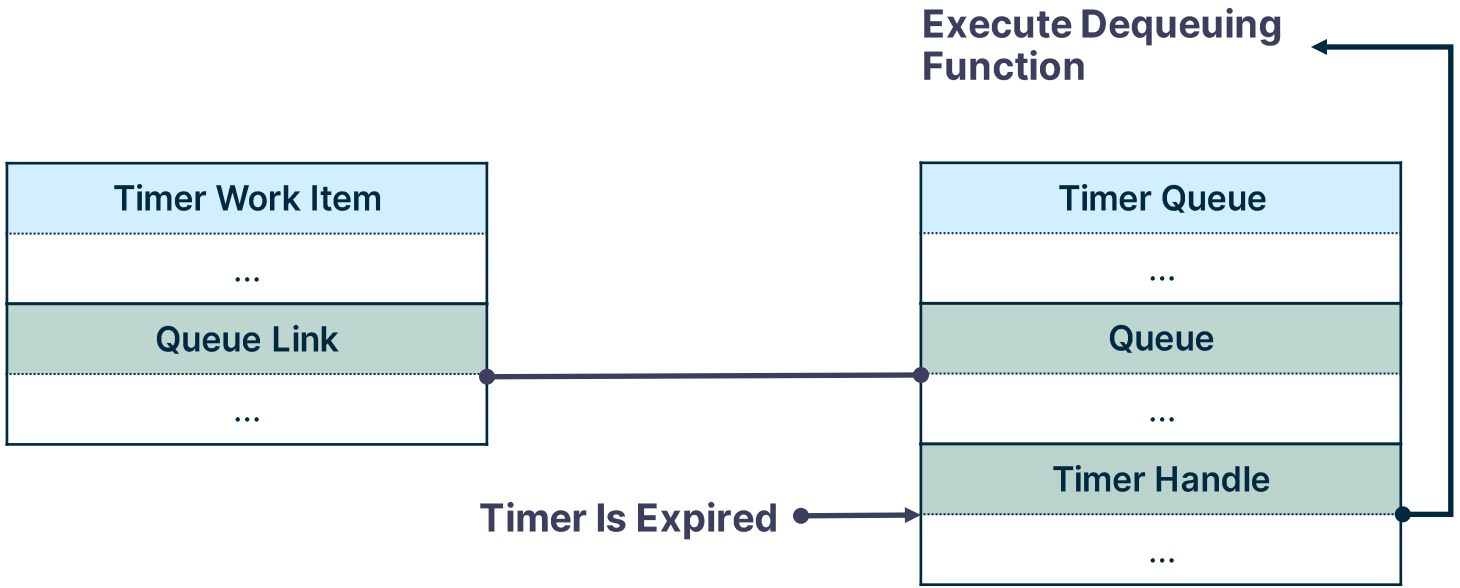
# Attacking Thread Pools – TP_TIMER



# Attacking Thread Pools – TP_TIMER



# Attacking Thread Pools – TP_TIMER



# Attacking Thread Pools - TP_TIMER

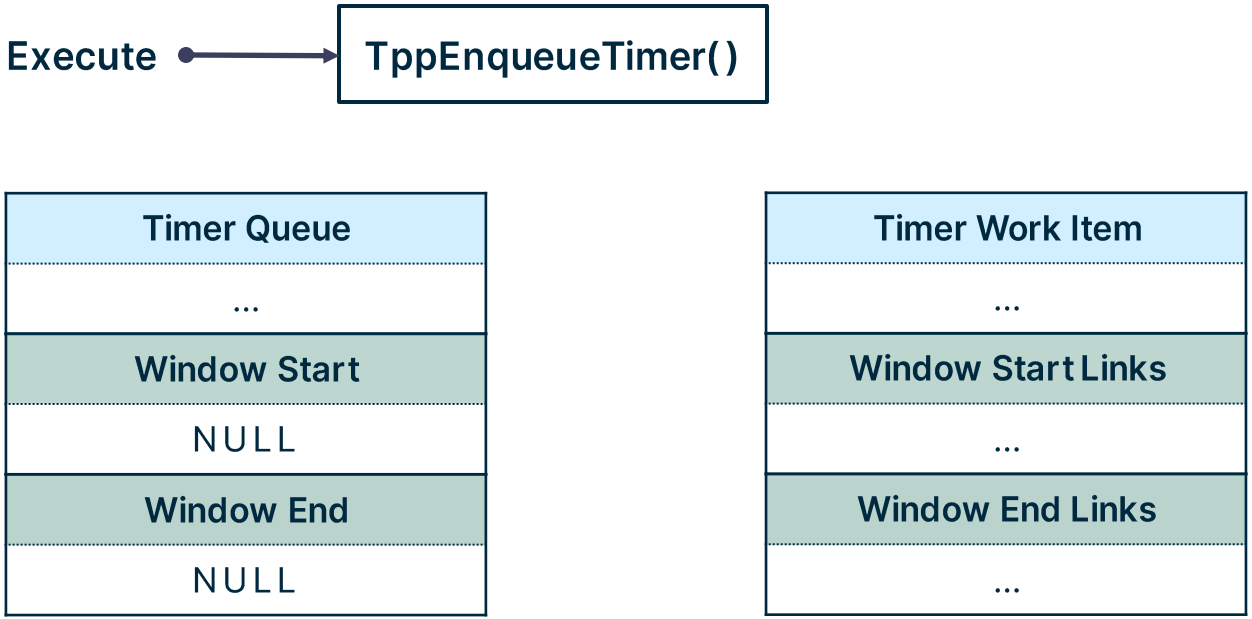
```
typedef struct _TP_TIMER
{
    [snip]
    TPP_PH_LINKS WindowEndLinks;
    TPP_PH_LINKS WindowStartLinks;
    [snip]
} TP_TIMER, * PTP_TIMER;
```

# Attacking Thread Pools - TP_TIMER

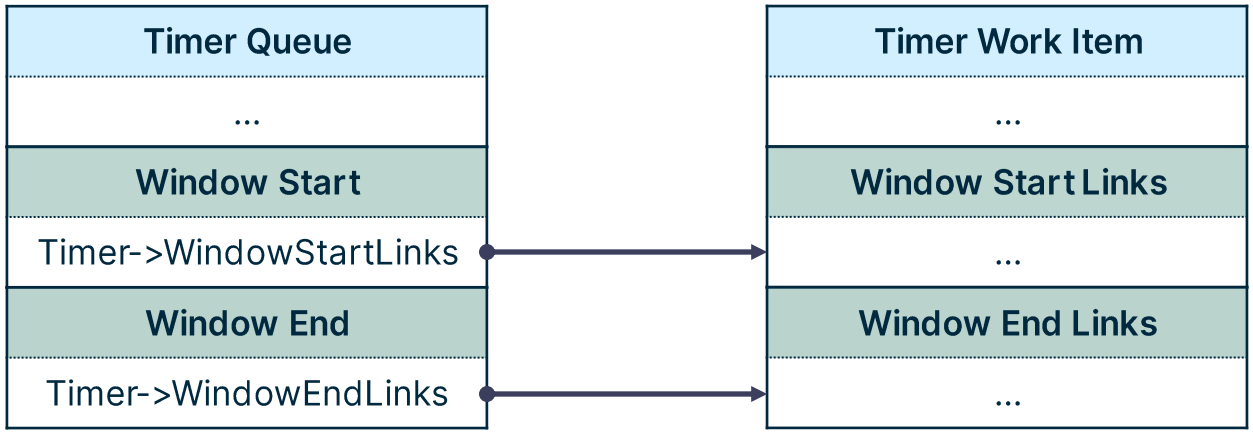
## **Ntdll::** TppEnqueueTimer

```
NTSTATUS NTAPI TppEnqueueTimer(TPP_TIMER_QUEUE* TimerQueue, TP_TIMER* TpTimer)
{
    [snip]
    TppPHInsert(&TimerQueue->WindowStart, &TpTimer->WindowStartLinks);
    TppPHInsert(&TimerQueue->WindowEnd, &TpTimer->WindowEndLinks);
    [snip]
}
```

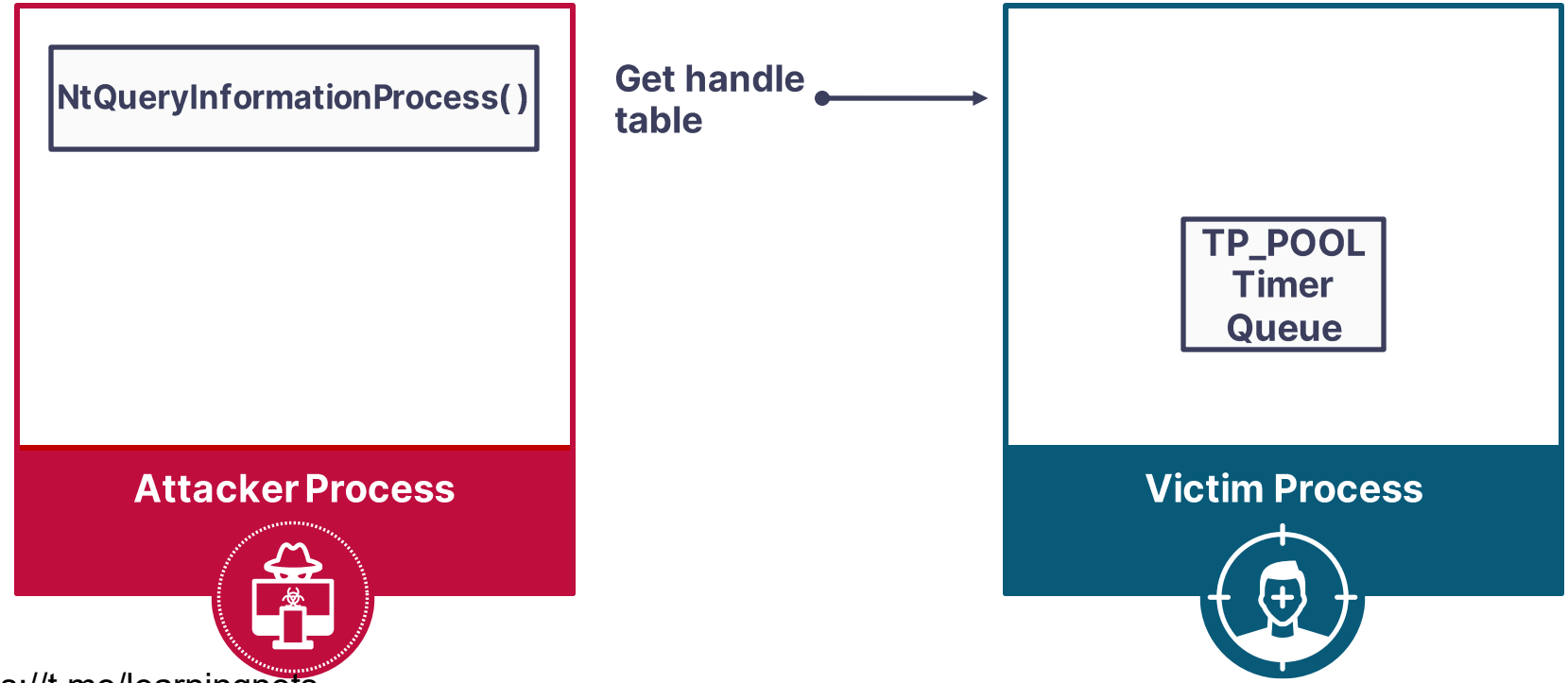
# Attacking Thread Pools – TP_TIMER



# Attacking Thread Pools – TP_TIMER



# Attacking Thread Pools – TP_TIMER



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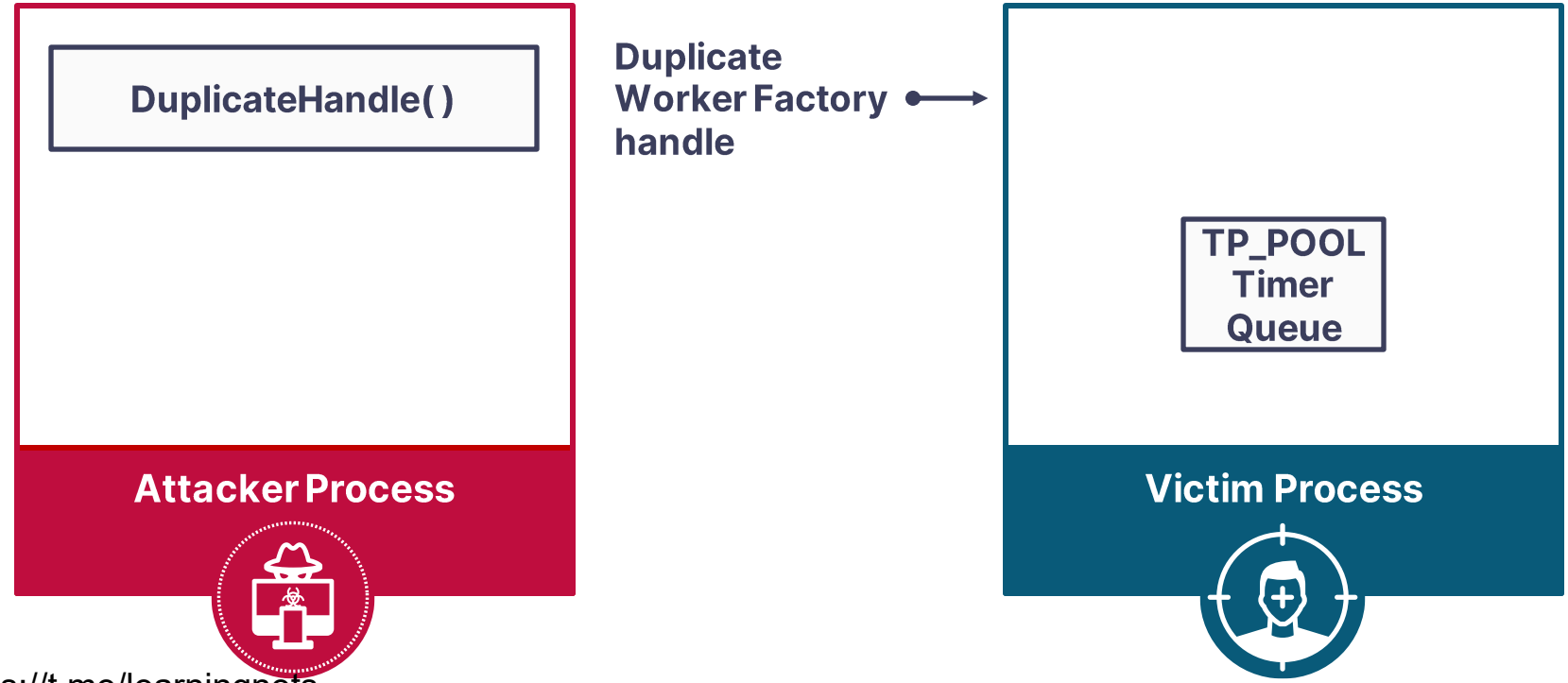

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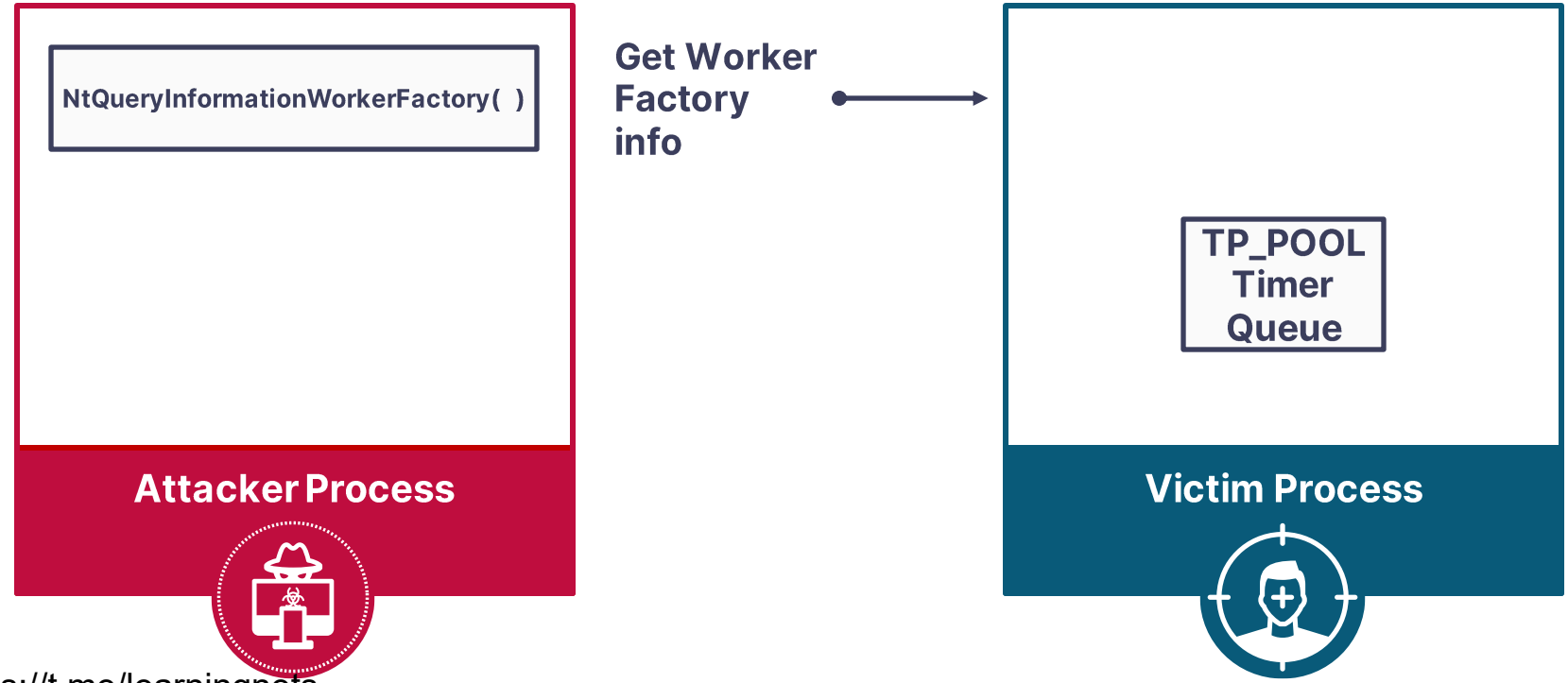
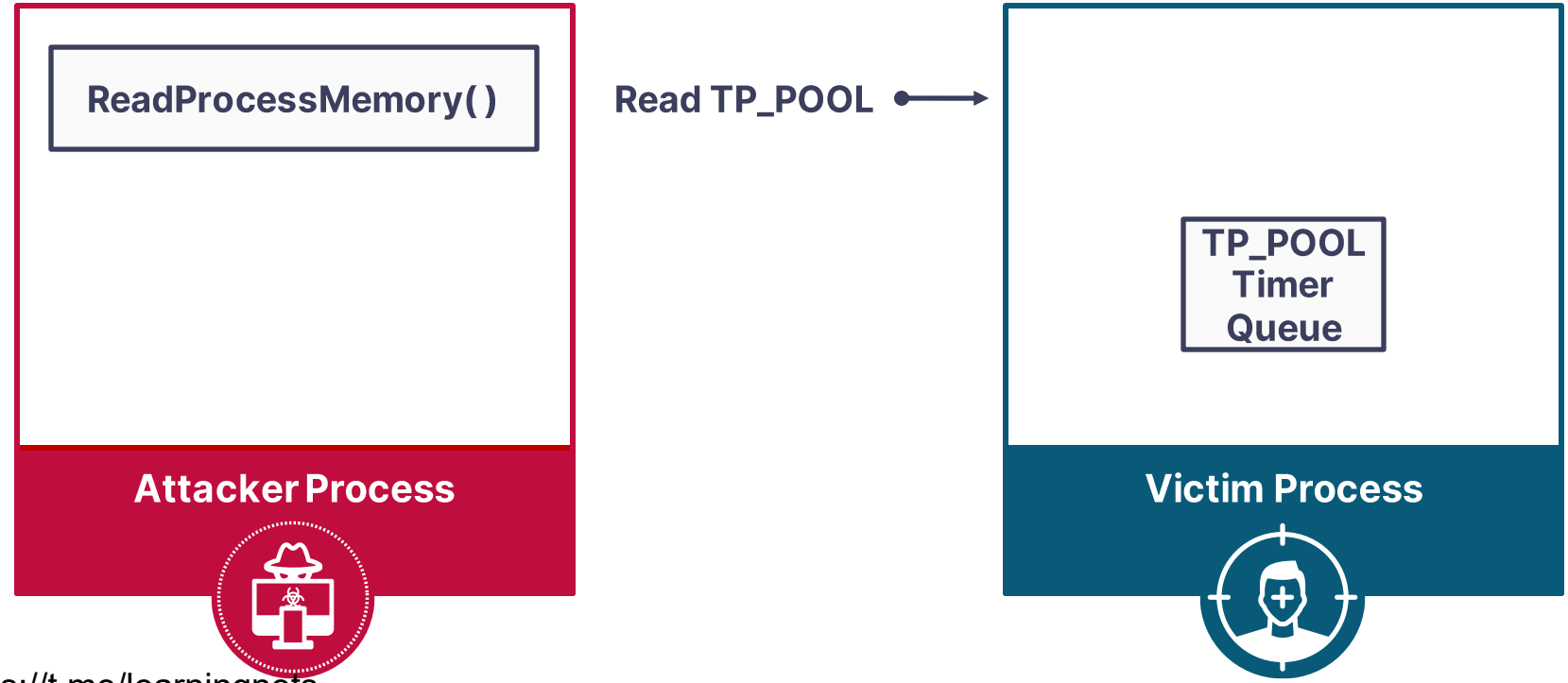
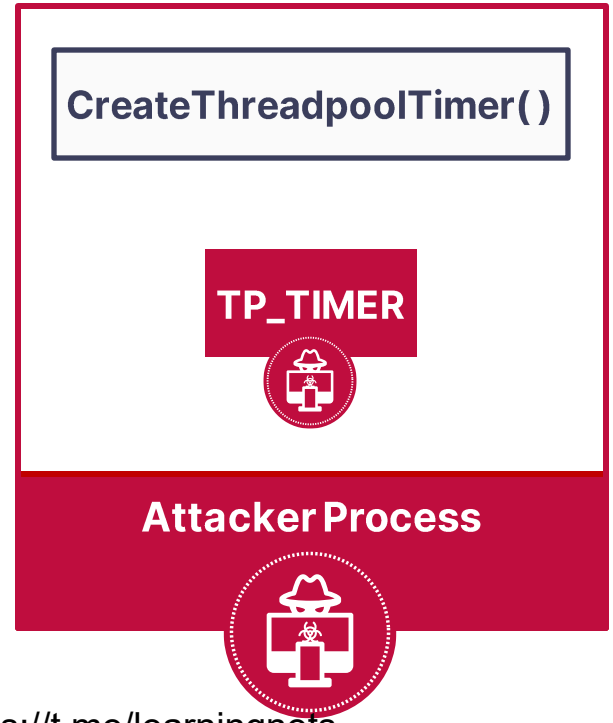
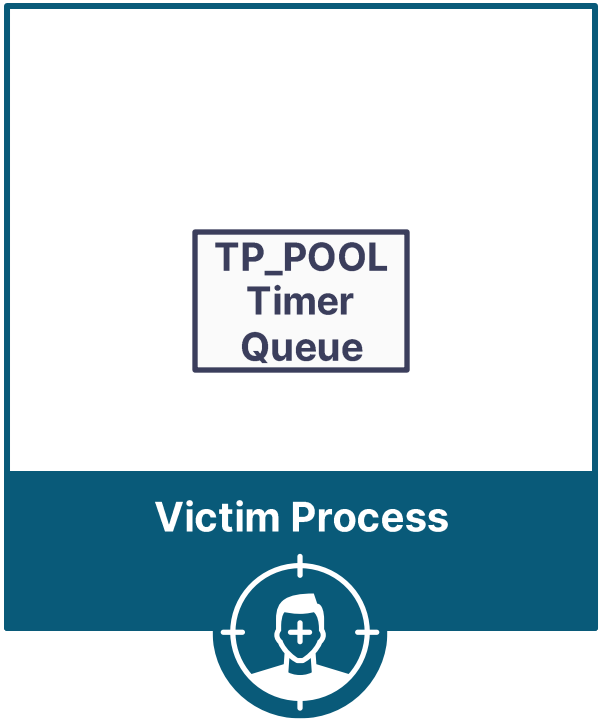


# Attacking Thread Pools – TP_TIMER

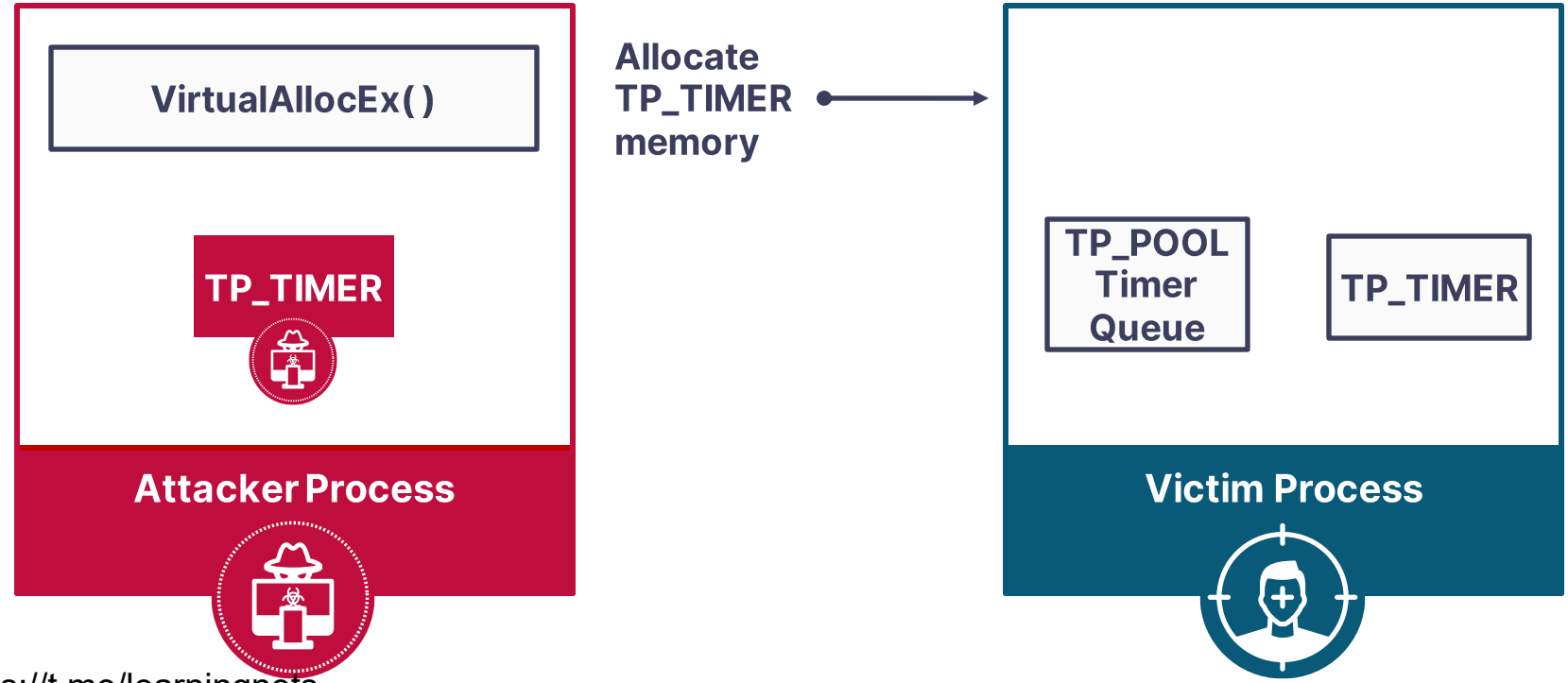


# Attacking Thread Pools – TP_TIMER



# Attacking Thread Pools – TP_TIMER



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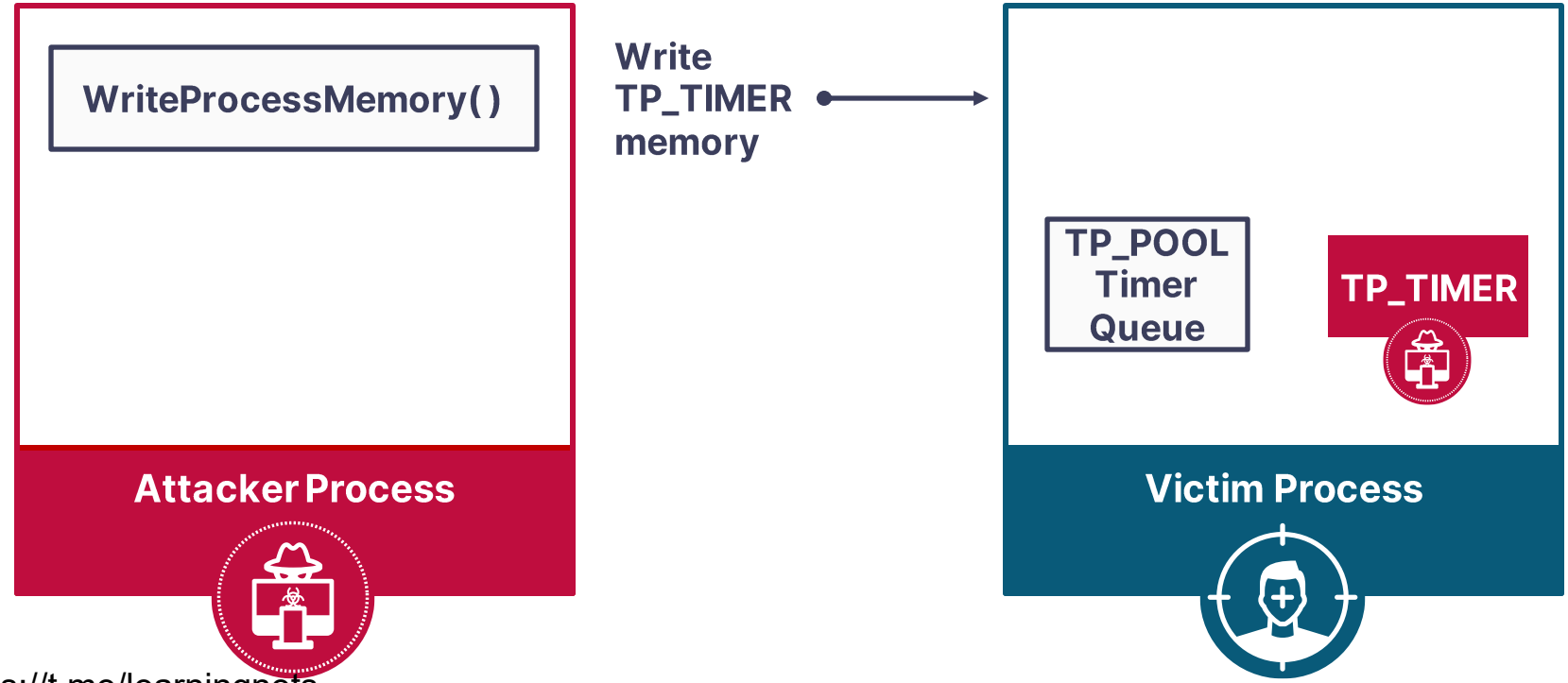
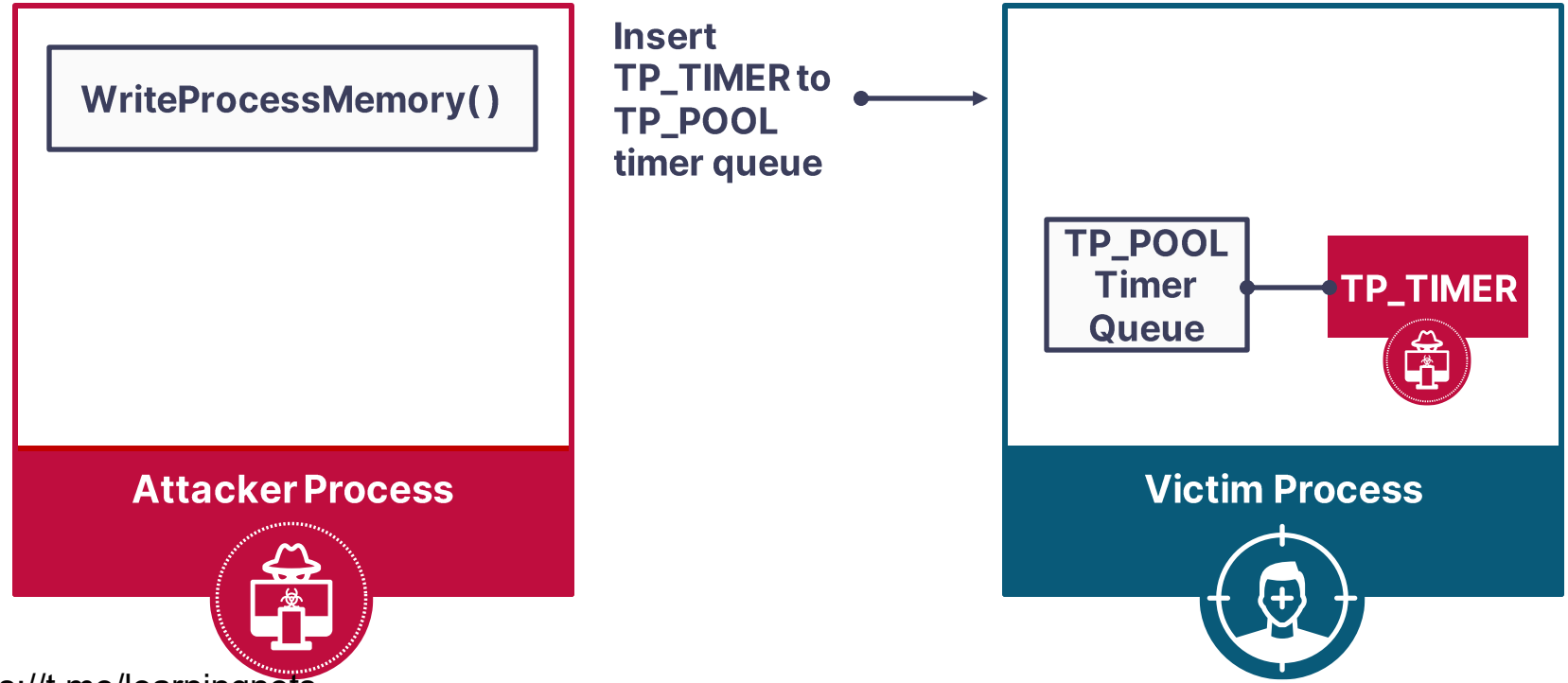


# Attacking Thread Pools – TP_TIMER



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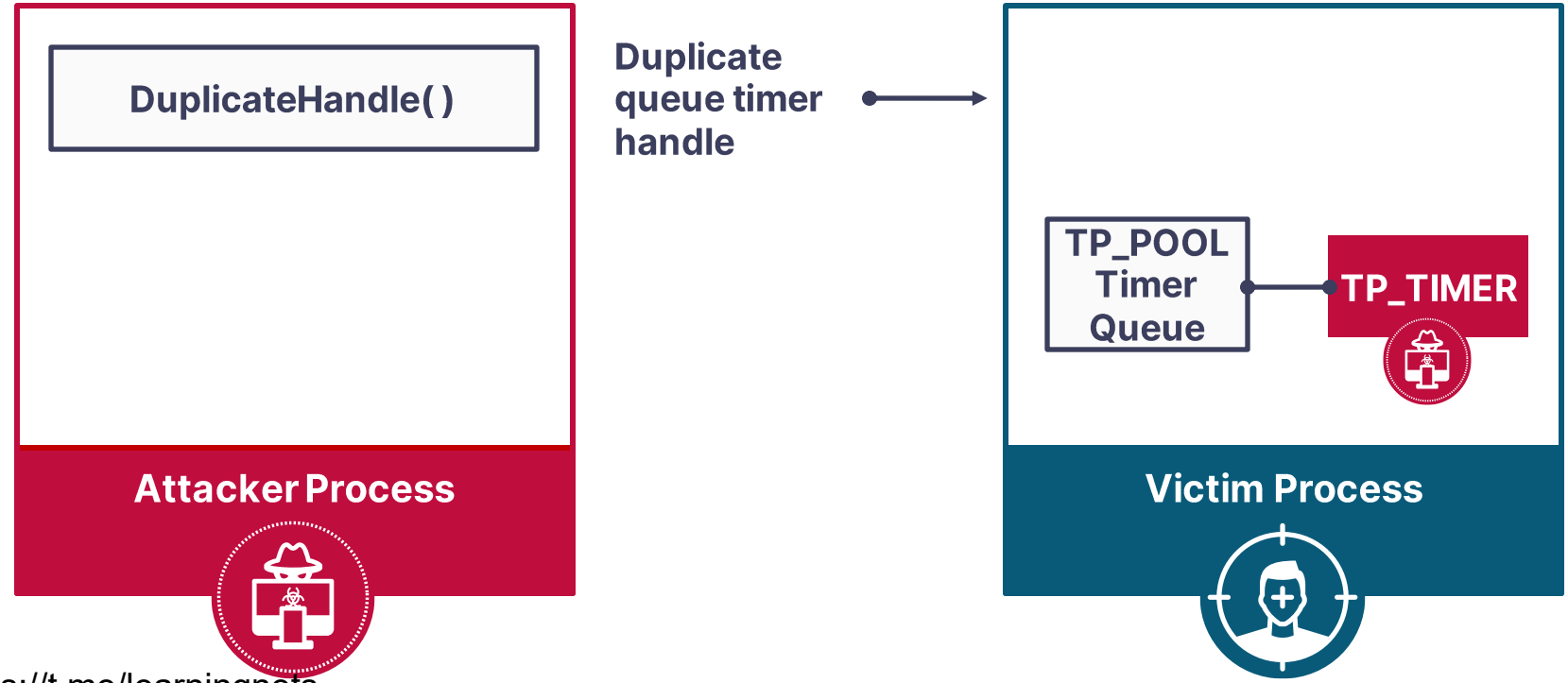
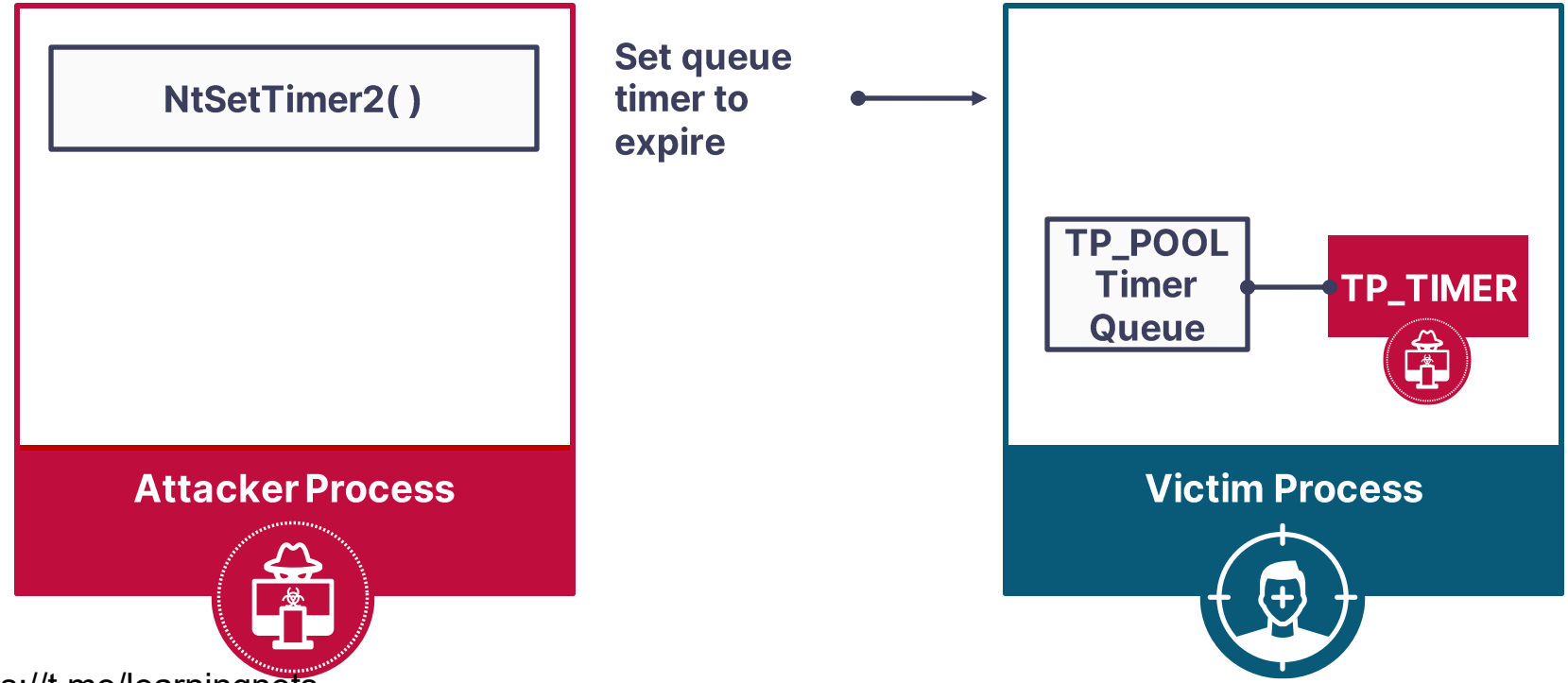


# Attacking Thread Pools – TP_TIMER



**PoolParty State**

# One new friend in the pool

# Introducing PoolParty

# Introducing PoolParty – Supported Variants

| | |
|---|---|
| **1** | Worker Factory Start Routine Overwrite |
| **2** | TP_WORK Insertion |
| **3** | TP_WAIT Insertion |
| **4** | TP_IO Insertion |
| **5** | TP_ALPC Insertion |
| **6** | TP_JOB Insertion |
| **7** | TP_DIRECT Insertion |
| **8** | TP_TIMER Insertion |

# Introducing PoolParty – Affected Products

- Palo Alto Cortex
- SentinelOne EDR
- CrowdStrike Falcon
- Microsoft Defender for Endpoint
- Cybereason EDR

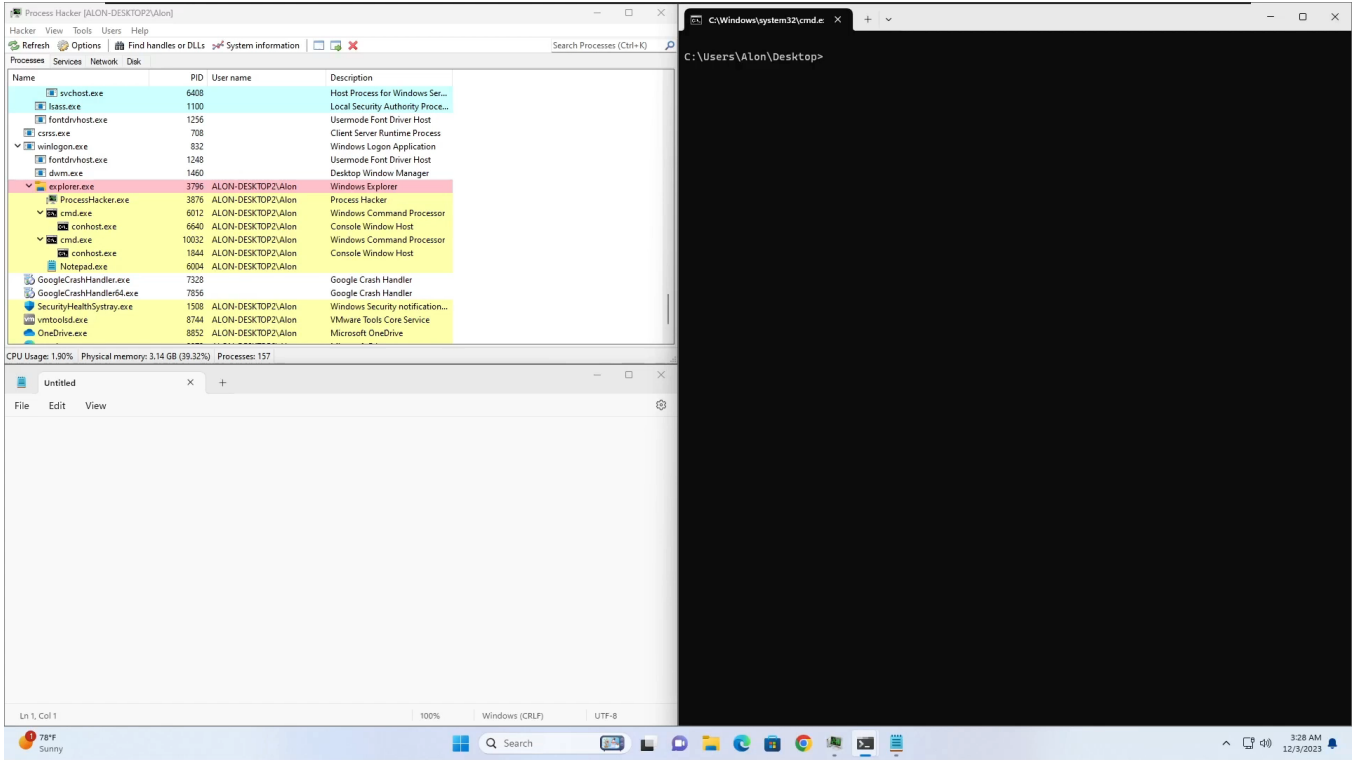
Figure 1: Magic Quadrant for Endpoint Protection Platforms


Source: Gartner (December 2022)

# Introducing PoolParty - GitHub Repository

**https://github.com/SafeBreach-Labs/PoolParty**

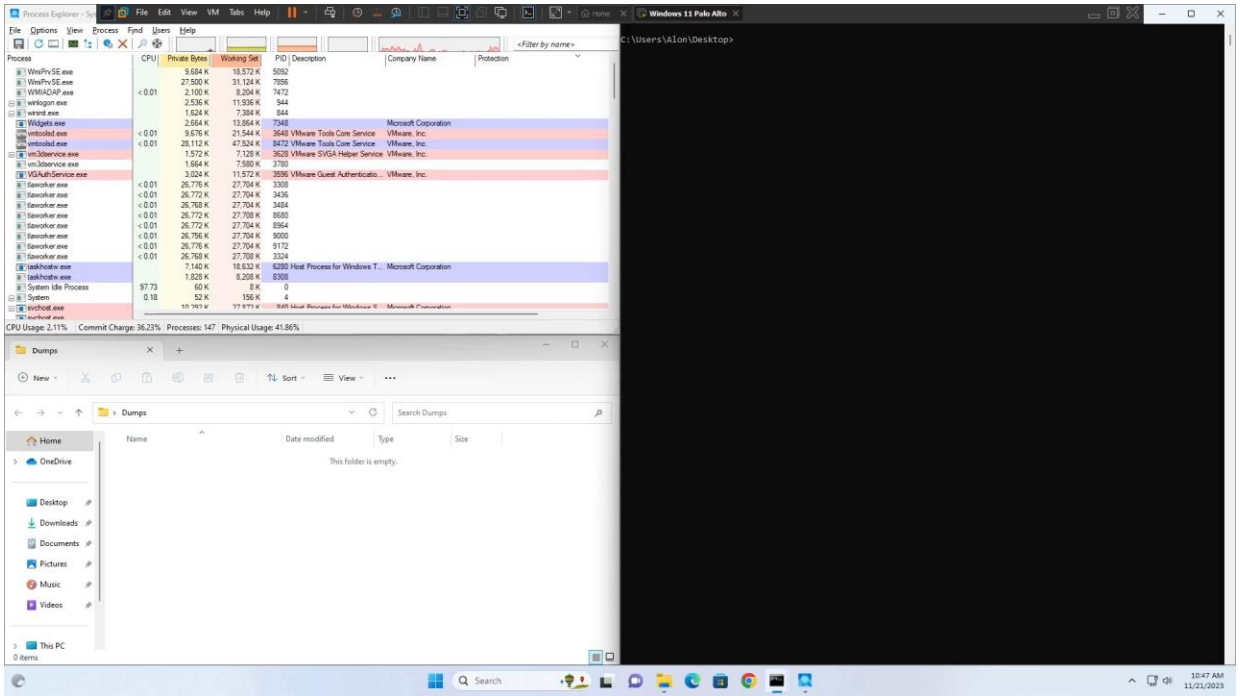
# Introducing PoolParty - Demo



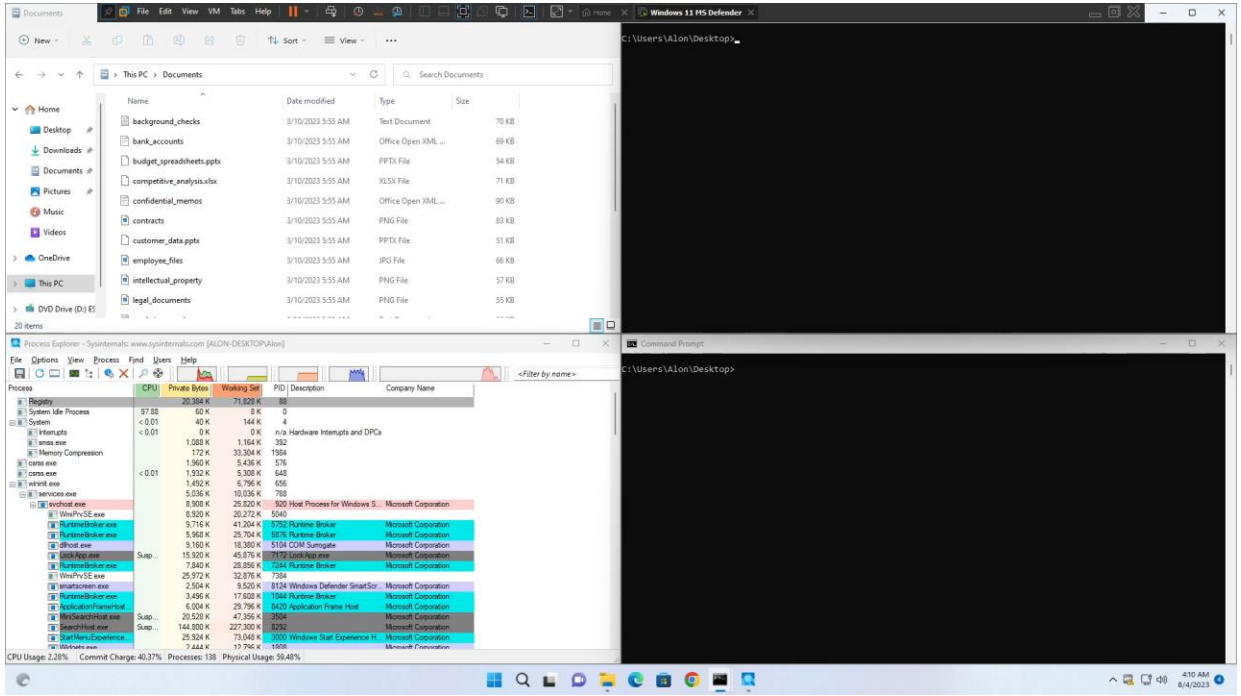
# How it started

# Process Injection Implications

# Process Injection Implications – Evasive Credential Dumping



# Process Injection Implications – Controlled Folder Access Bypass



# Takeaways

# Takeaways

We need a generic detection approach for process injections

The impact of process injections is larger than we thought

Enhance your focus on detecting anomalies rather than placing complete trust in processes based solely on their identity

# Q & A

https://github.com/SafeBreach-Labs/PoolParty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