The Pool Party You Will Never Forget:

New Process Injection Techniques Using Windows Thread Pools

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Self-taught

OS internals, reverse engineering and vulnerability research

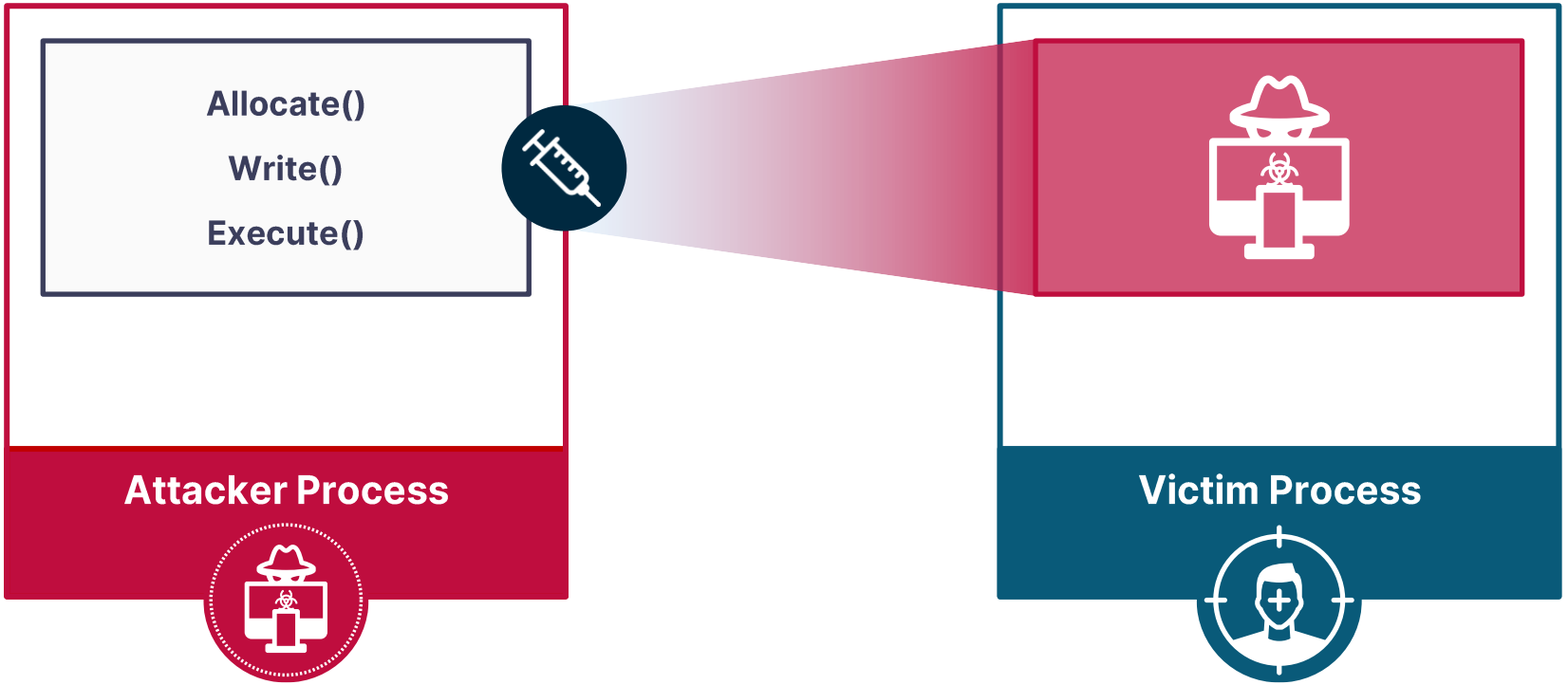
Former BJJ world and european champion

Agenda

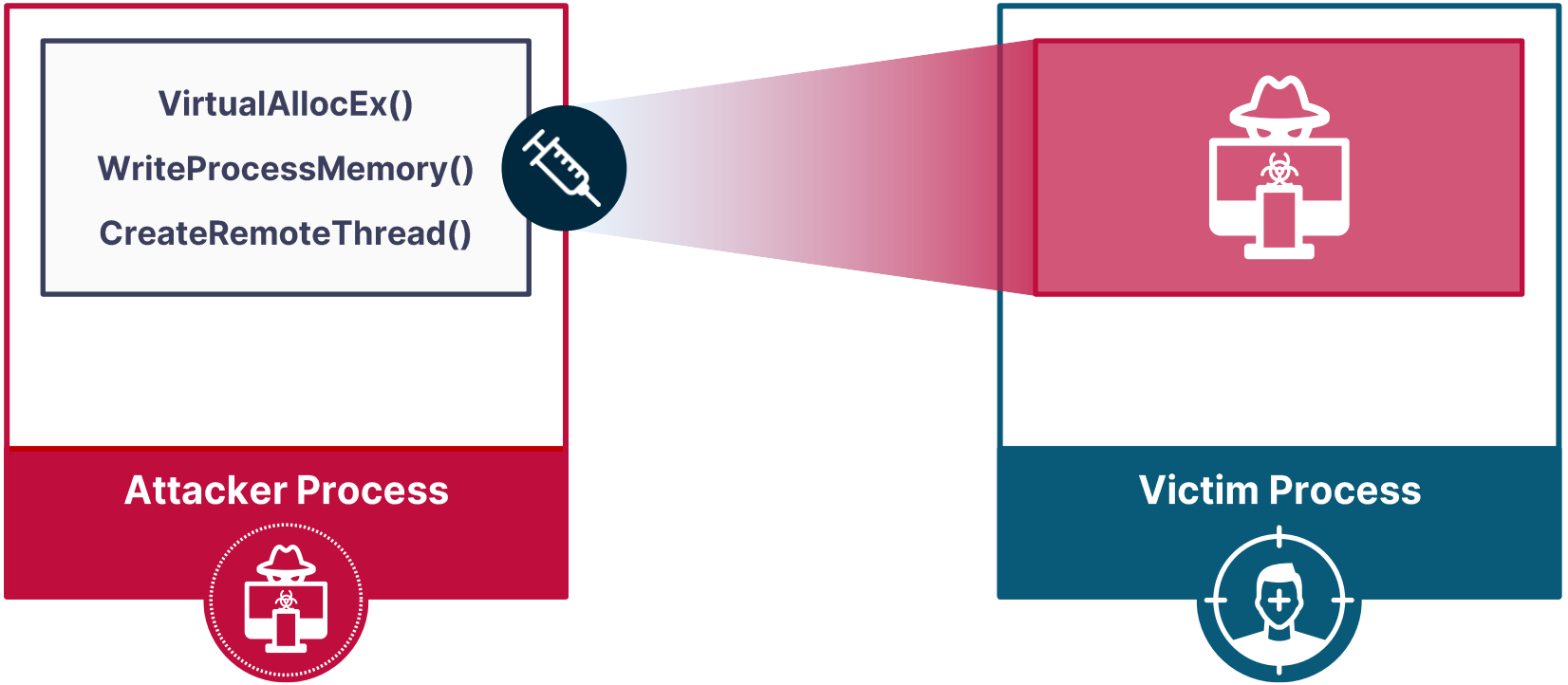
- Process Injection Background
- Research Motivation & Questions
- Detection Approach
- Research Goals
- User-mode Thread Pool Deep Dive
- Introducing PoolParty
- Process Injection Implications
- Takeaways

Process Injection Background

Process Injection Background



Process Injection Background



Motivation

Motivation

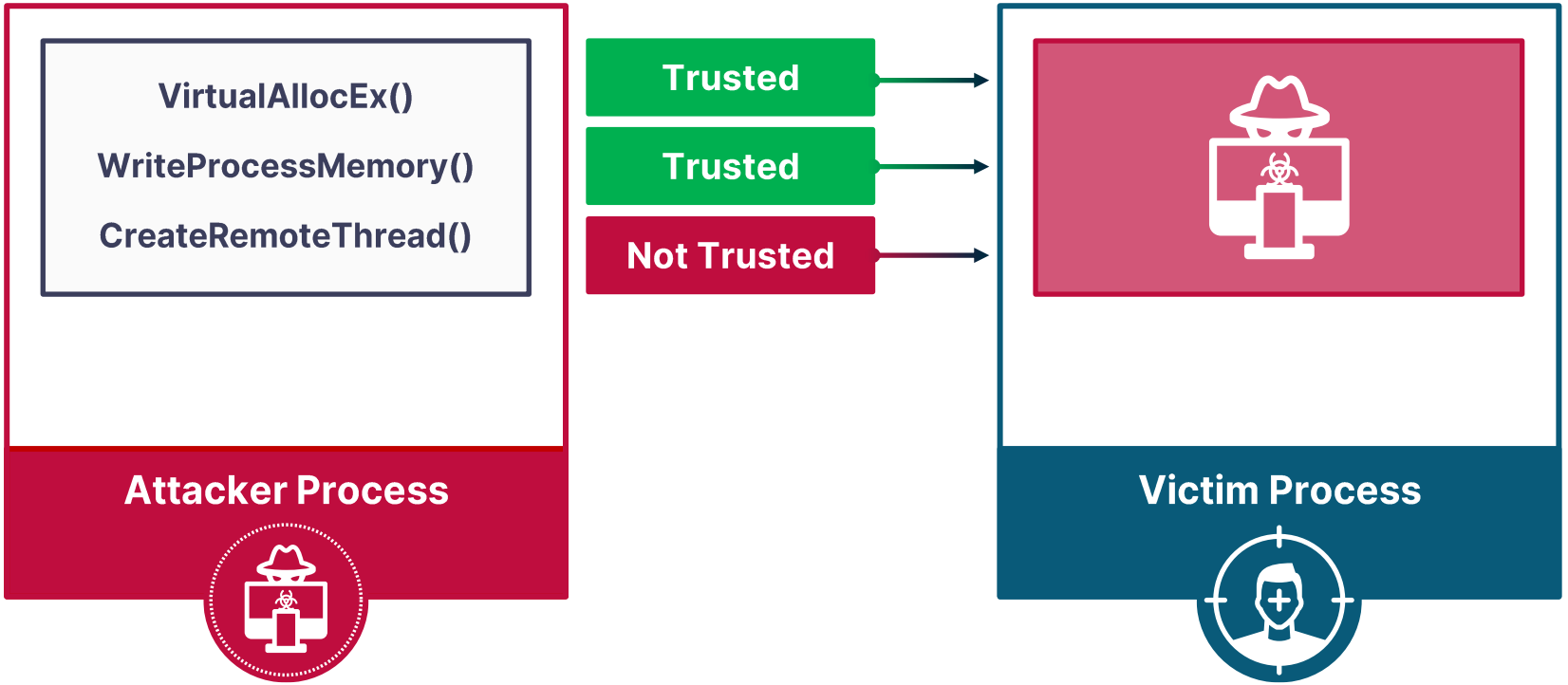
Process injection techniques abuses legitimate features of the OS

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

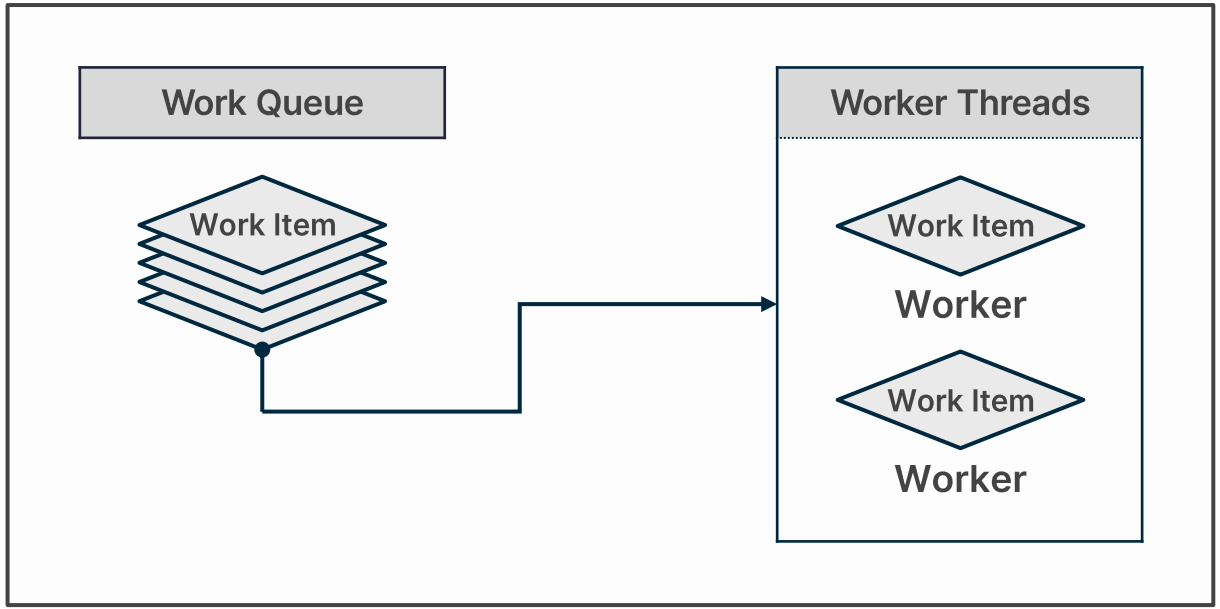
What if the execute primitive is built with write and allocate primitives?

What if the execution is triggered by a legitimate action?

What Is a Thread Pool?

What Is a Thread Pool?

How a Thread Pool Works?



Why Thread Pool?

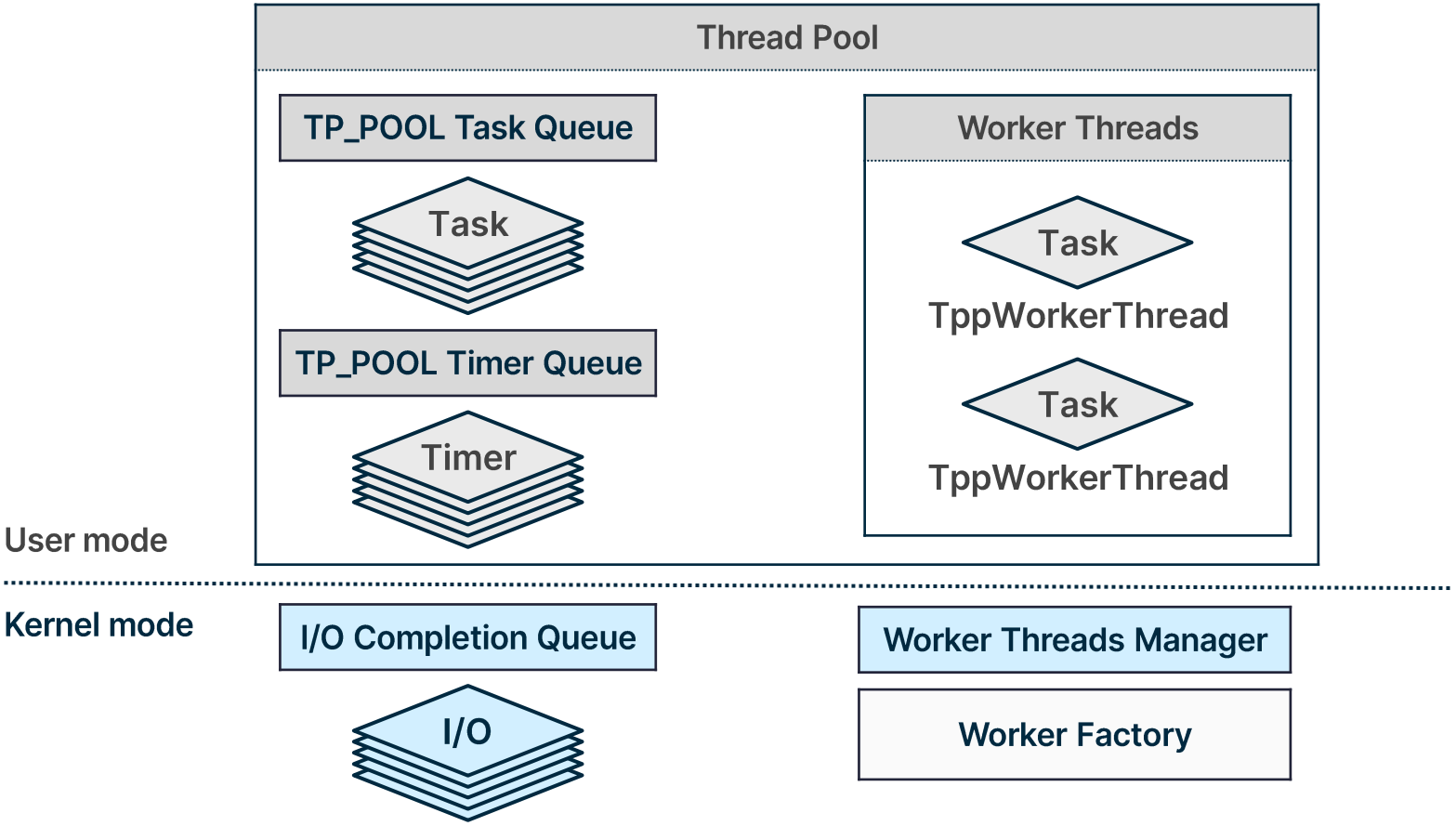
All processes have a thread pool by default

Work items and thread pools are represented by structures

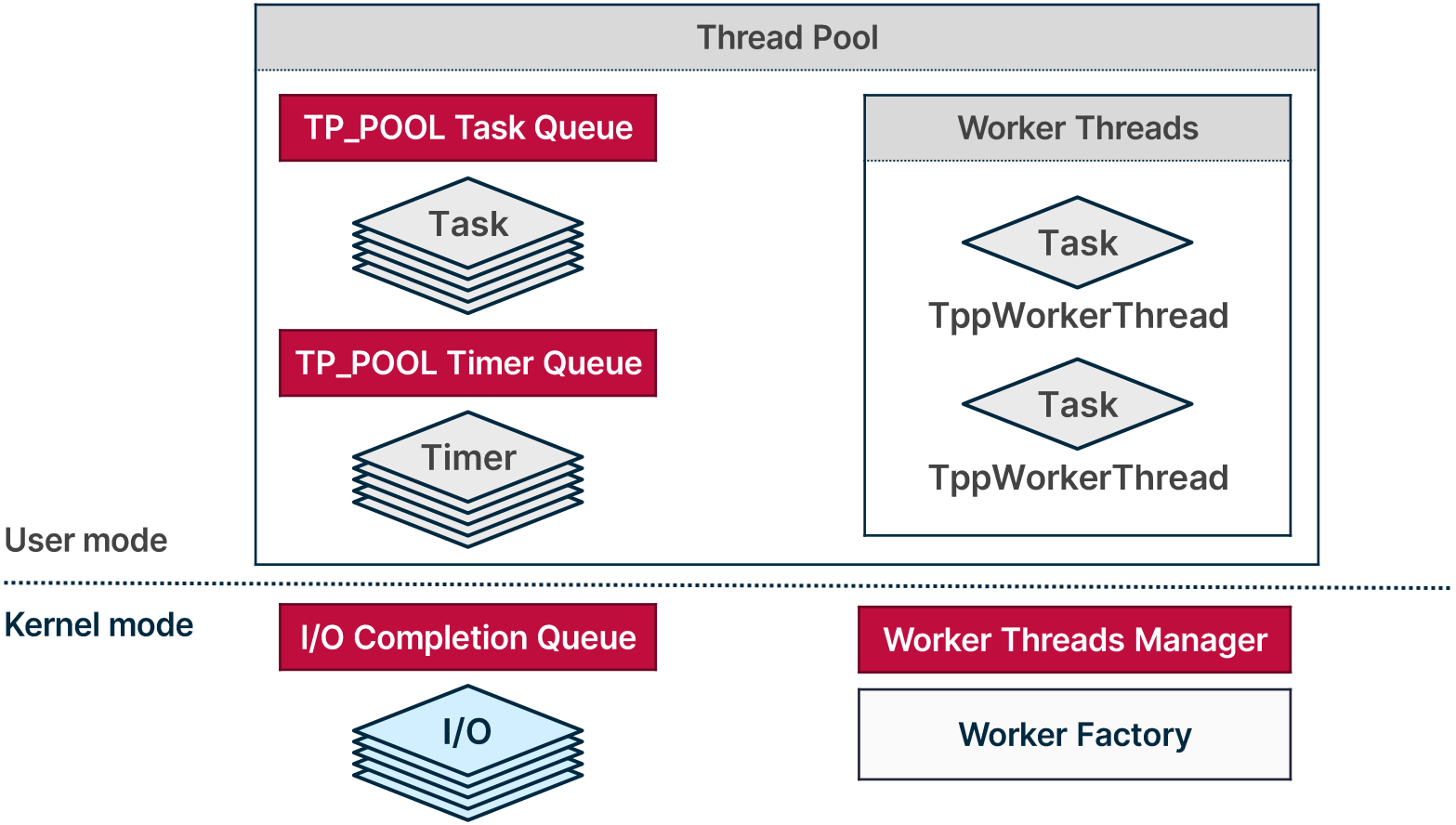
Multiple work item types are supported

User-Mode Thread Pool Deep Dive

User-Mode Thread Pool Architecture



Defining Attack Surface

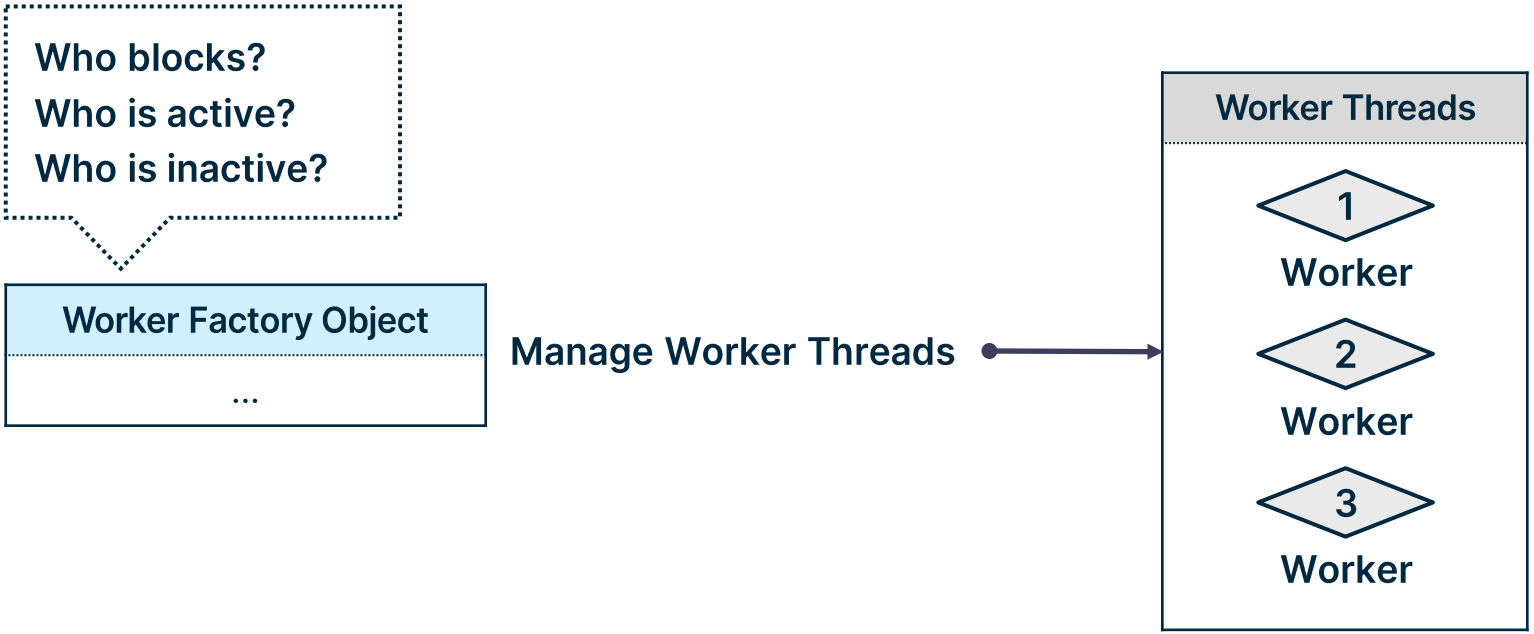


PoolParty State

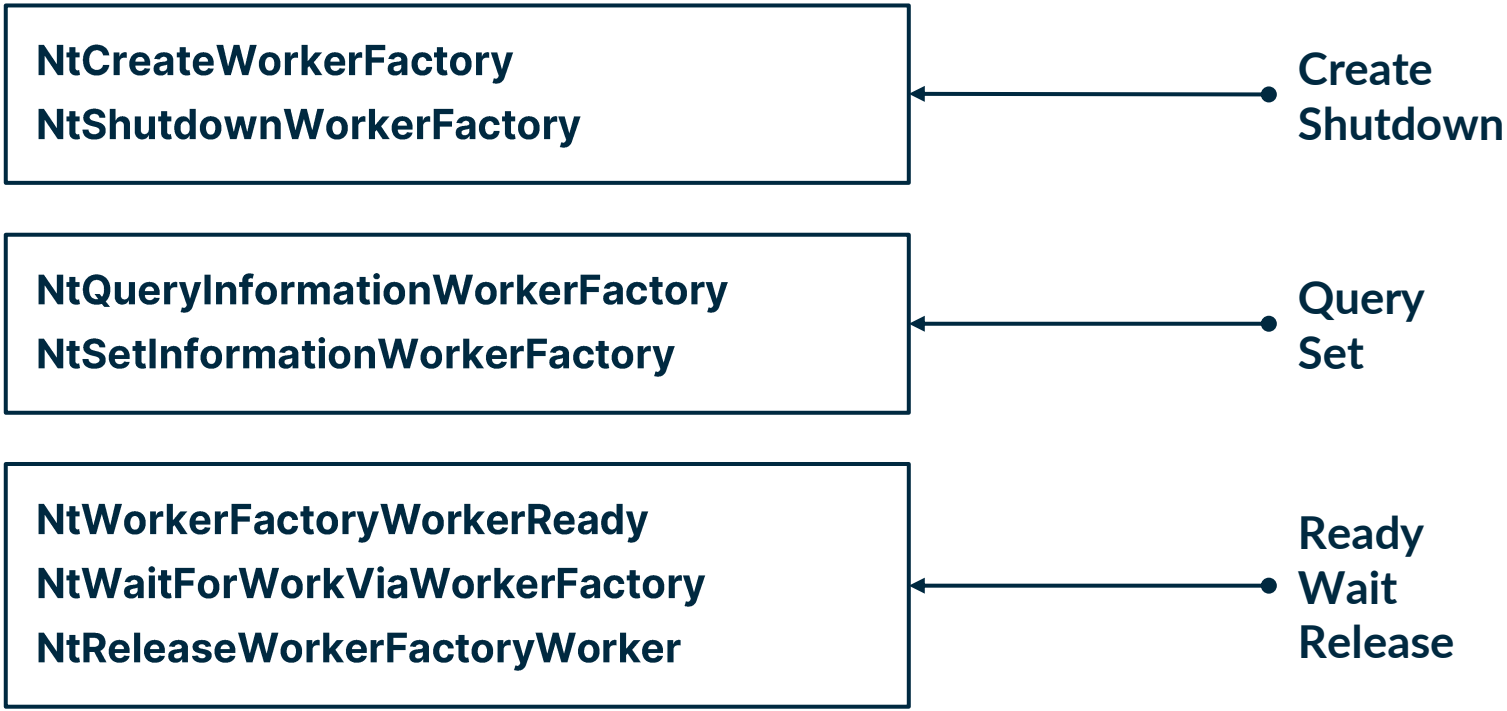
No friends in the pool

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

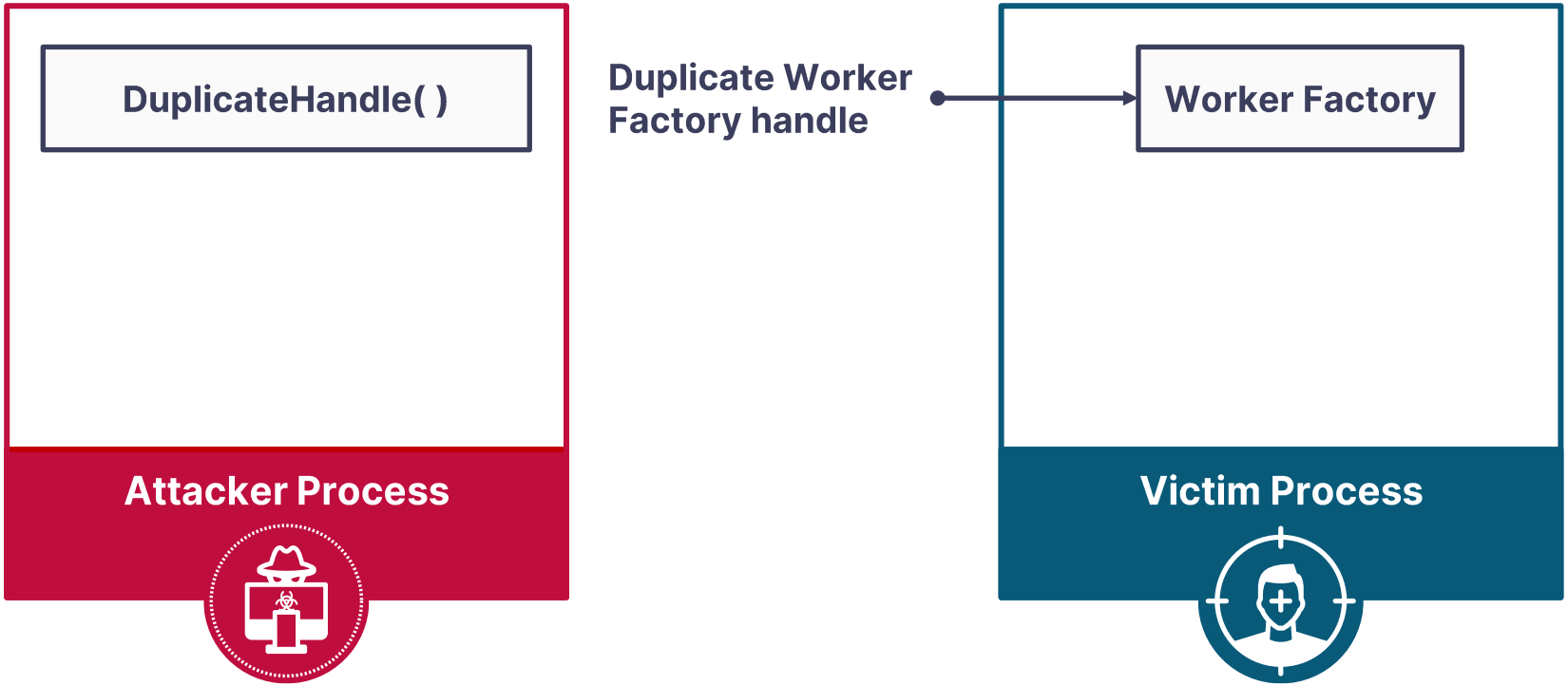
```
NTSTATUS NTAPI NtCreateWorkerFactory(..., HANDLE WorkerProcessHandle, ...)
{
    [snip]

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

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

    [snip]
}
```

Attacking Worker Factories



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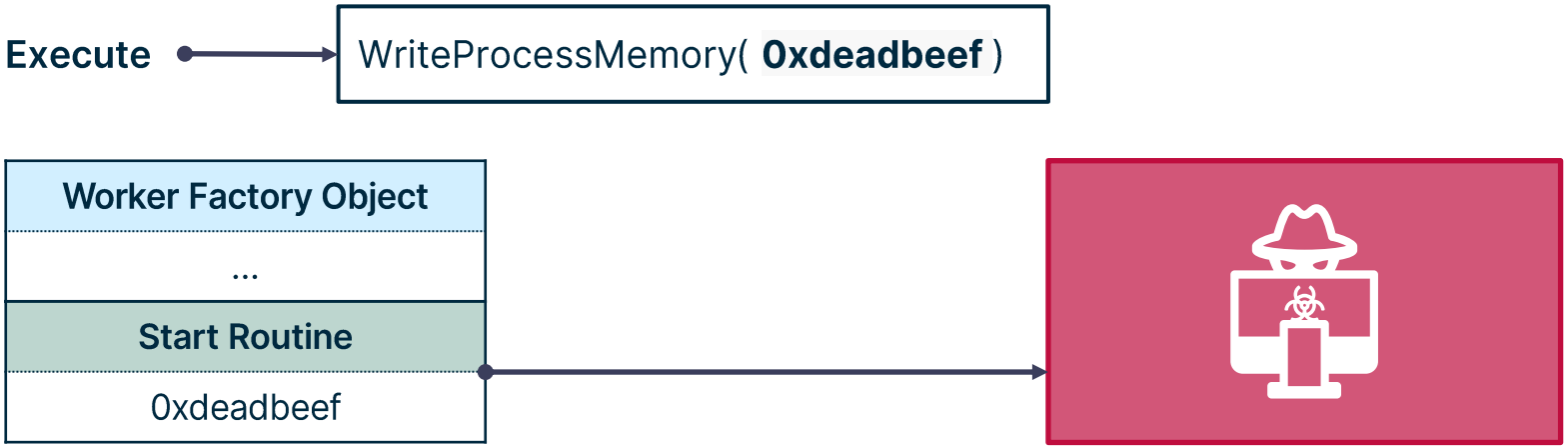


Attacking Worker Factories

```
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;
```

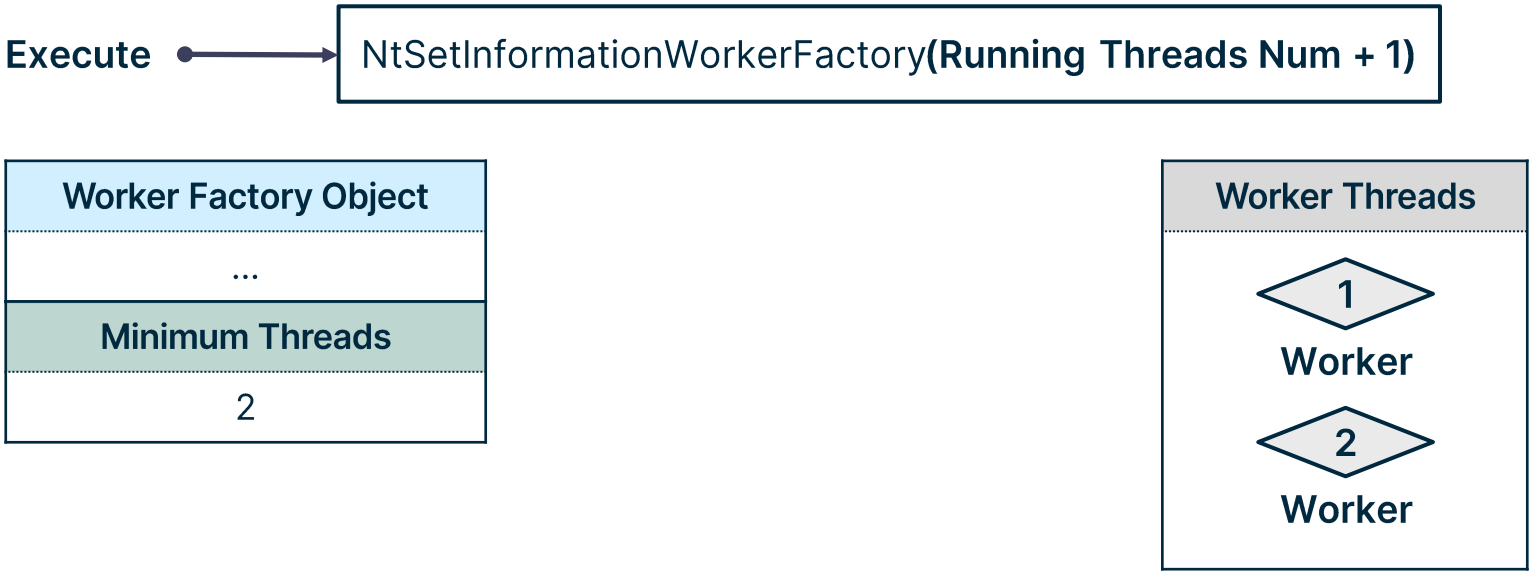
Attacking Worker Factories

```
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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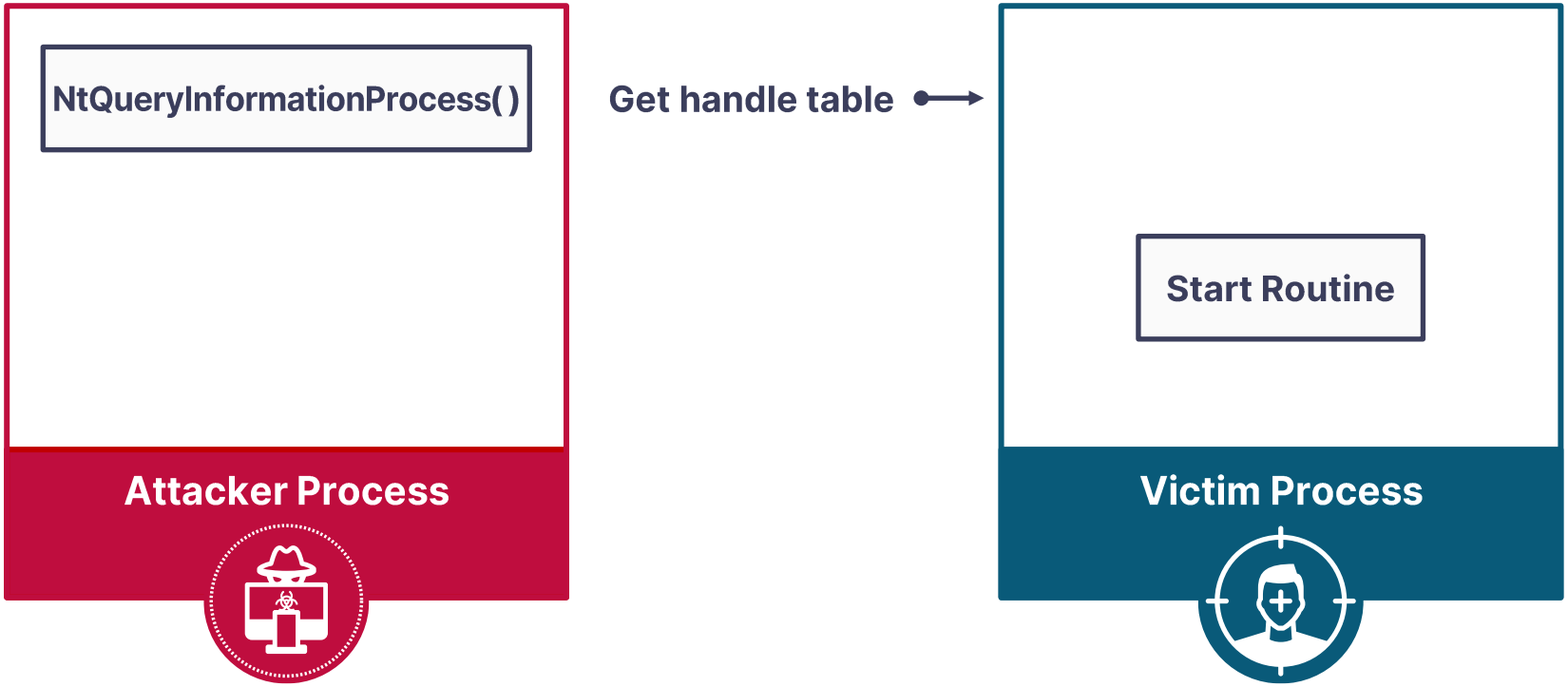

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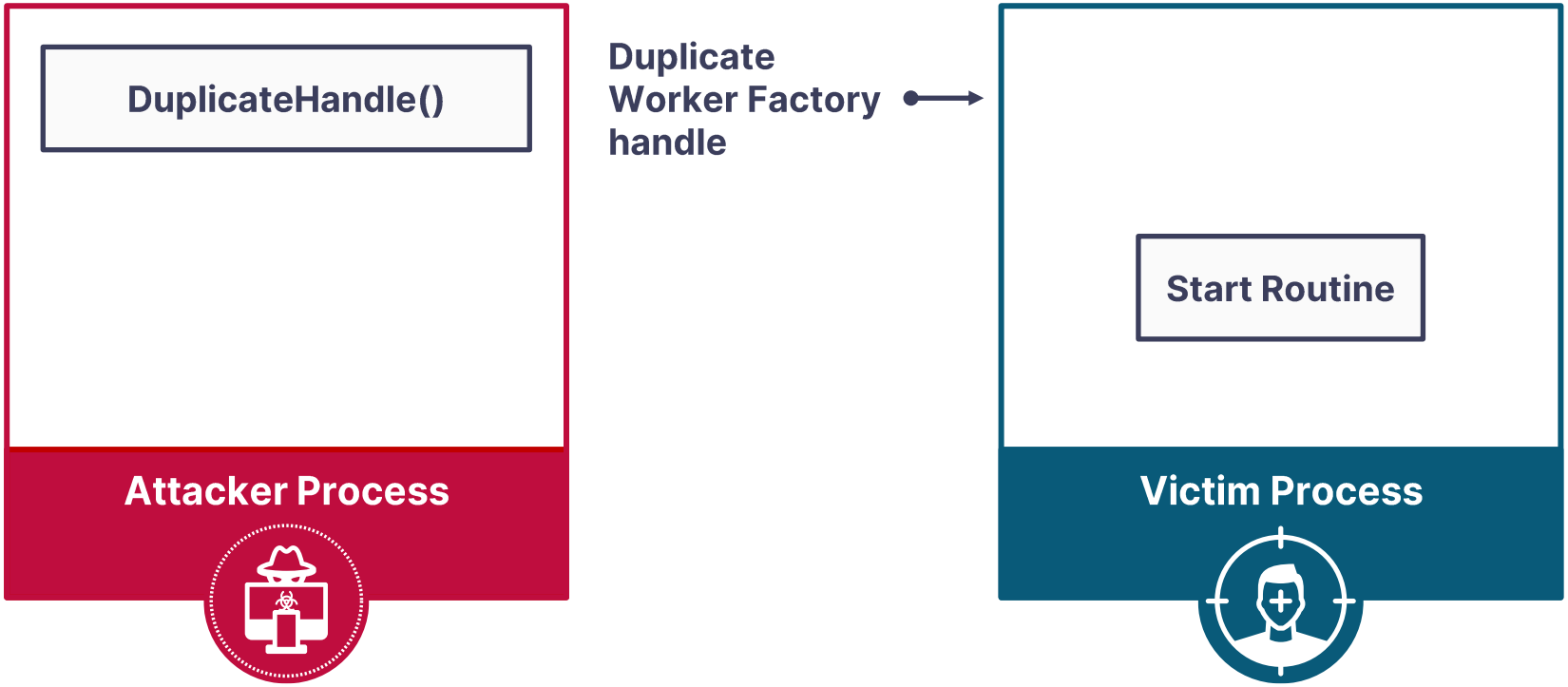

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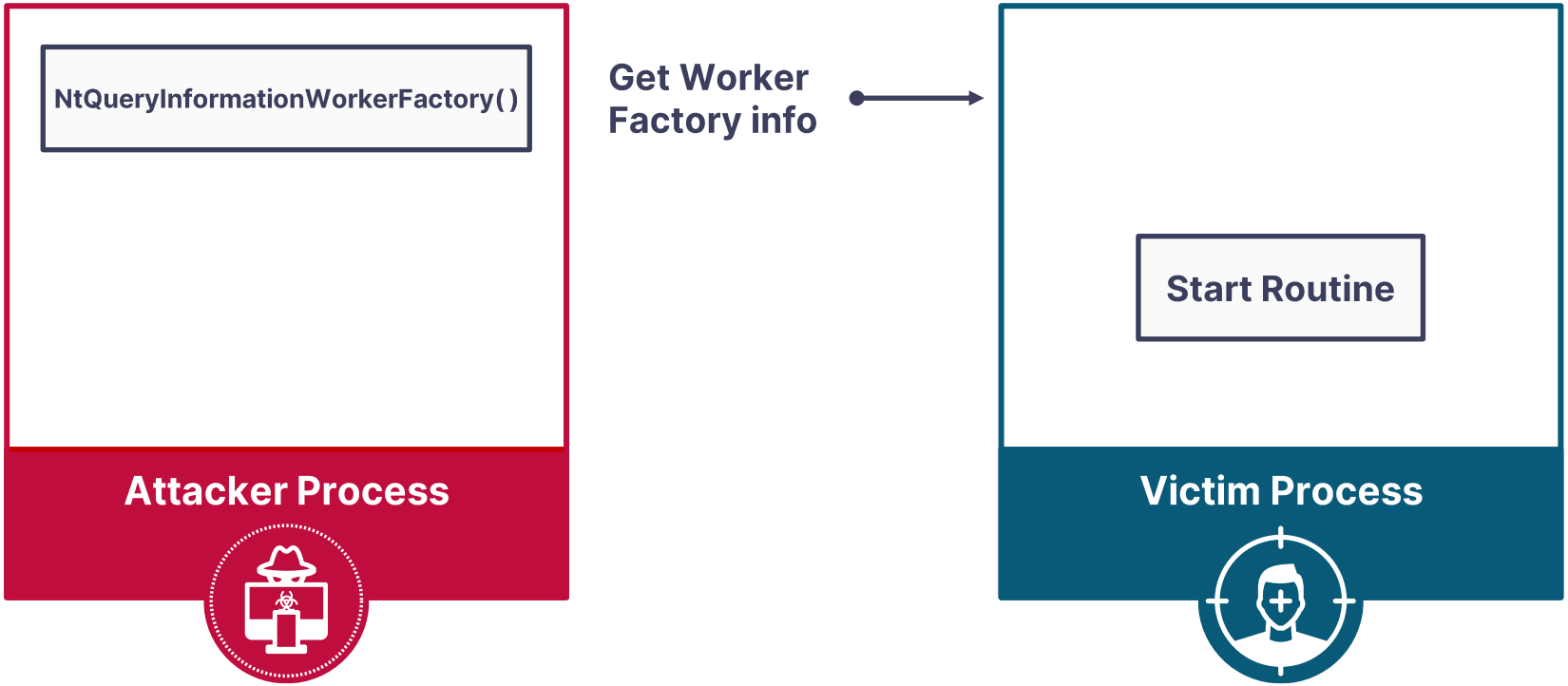

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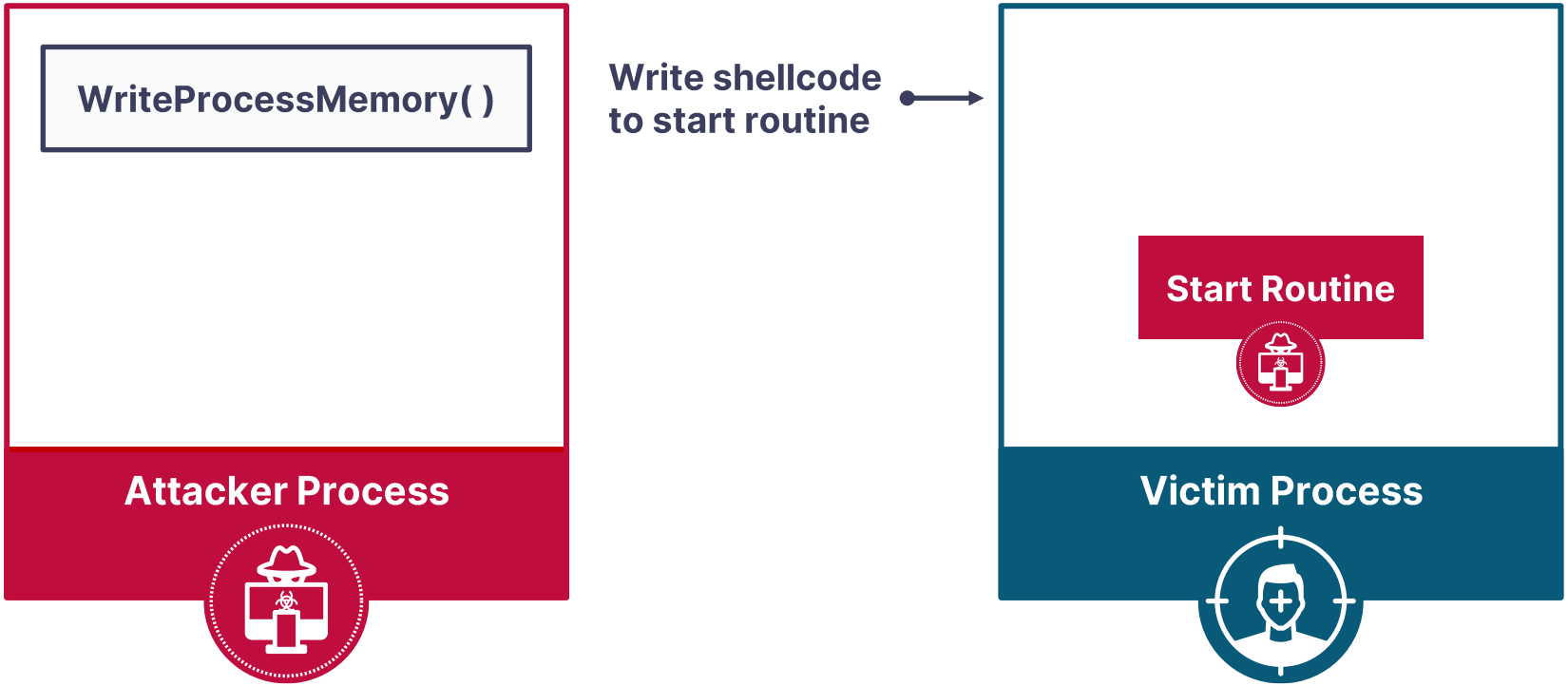
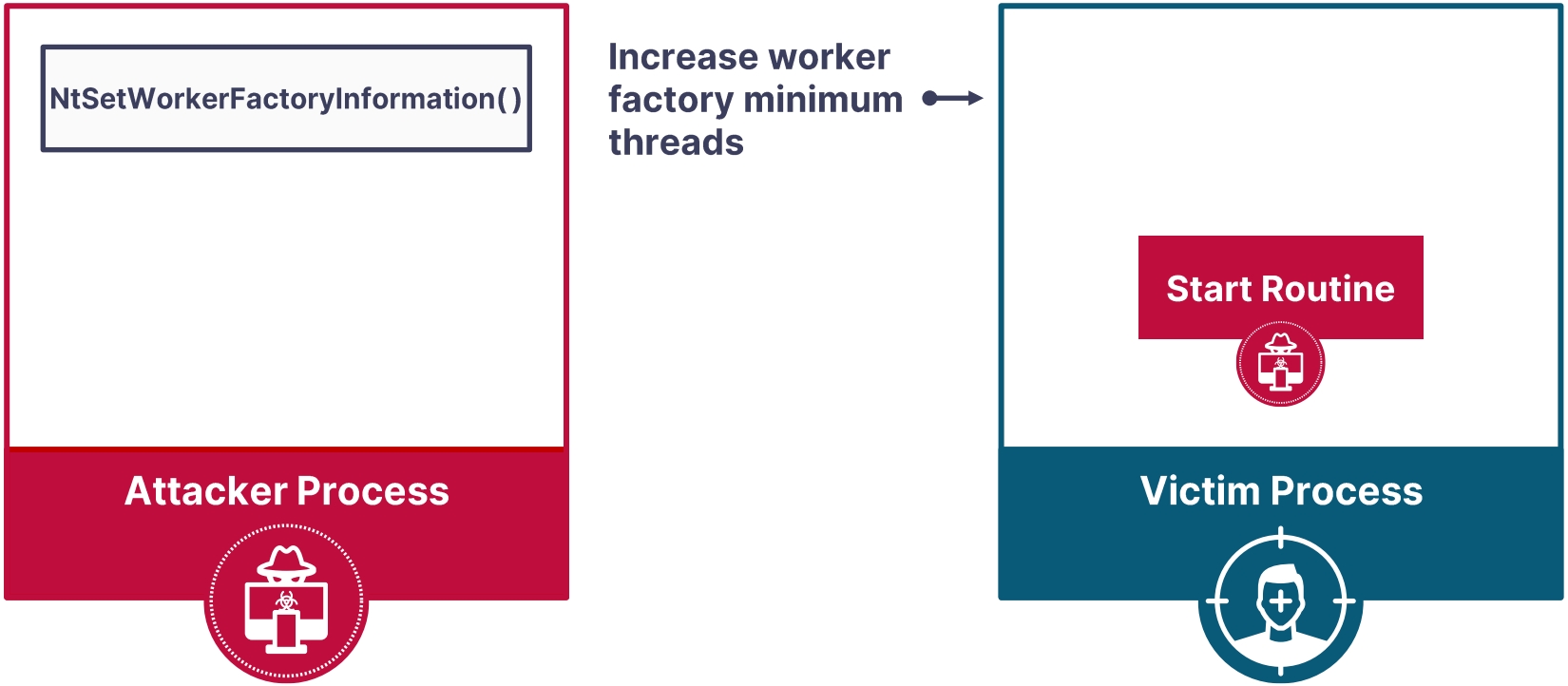


Attacking Worker Factories



PoolParty State

First friend in the pool

Attacking Thread Pools

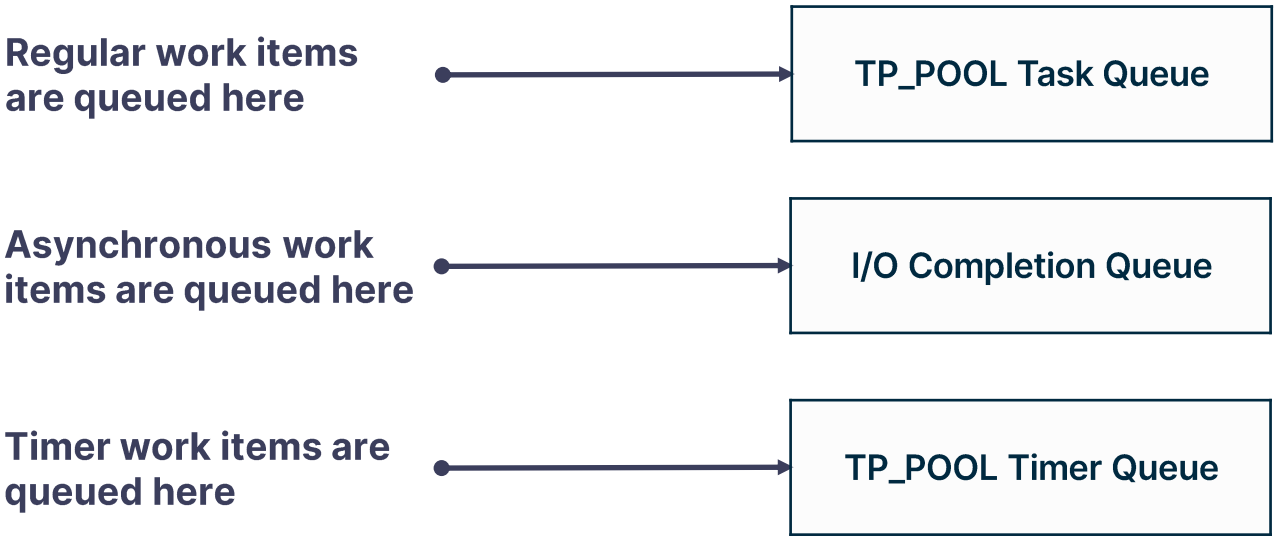
Attacking Thread Pools

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

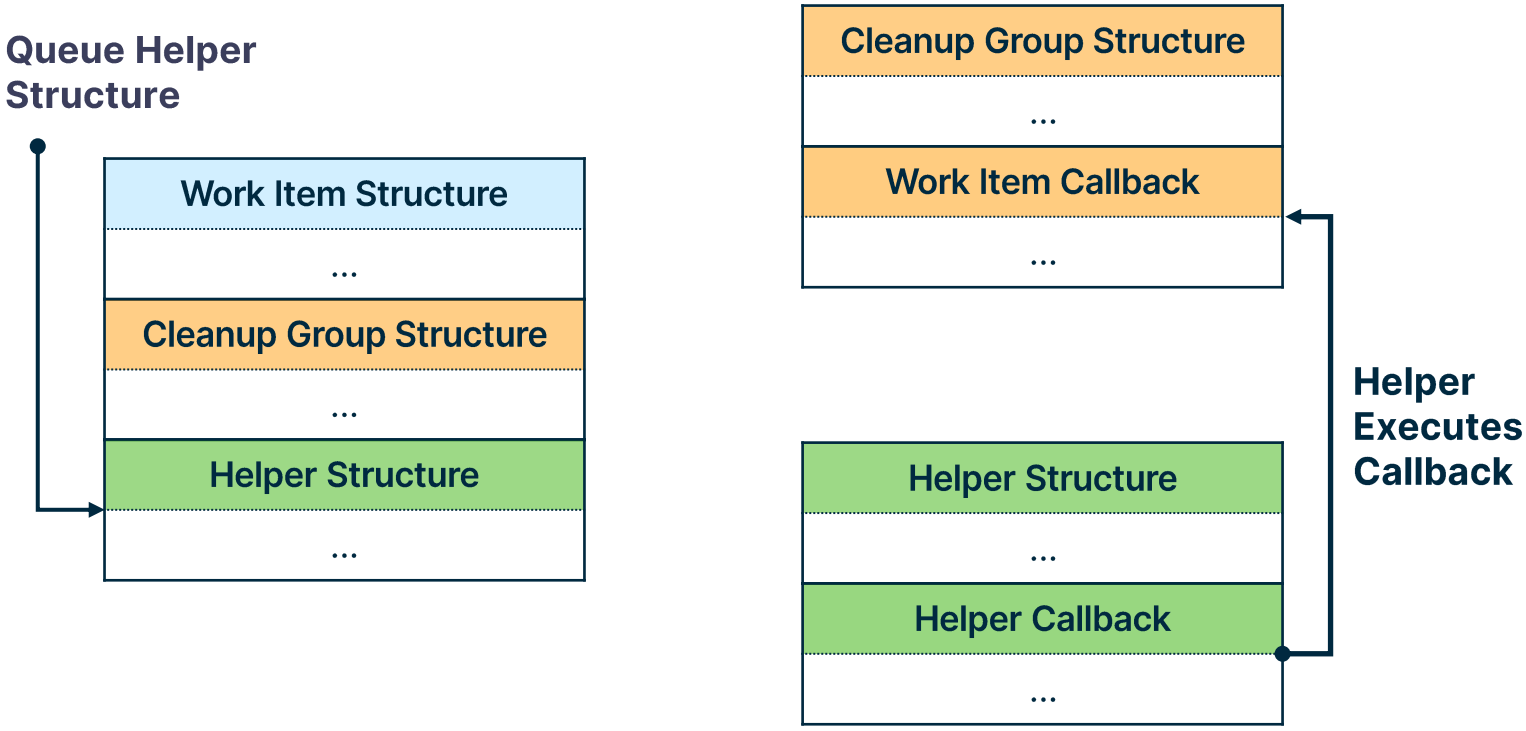
Attacking Thread Pools - Work Item Types

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
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

Ntdll:: TpPostTask

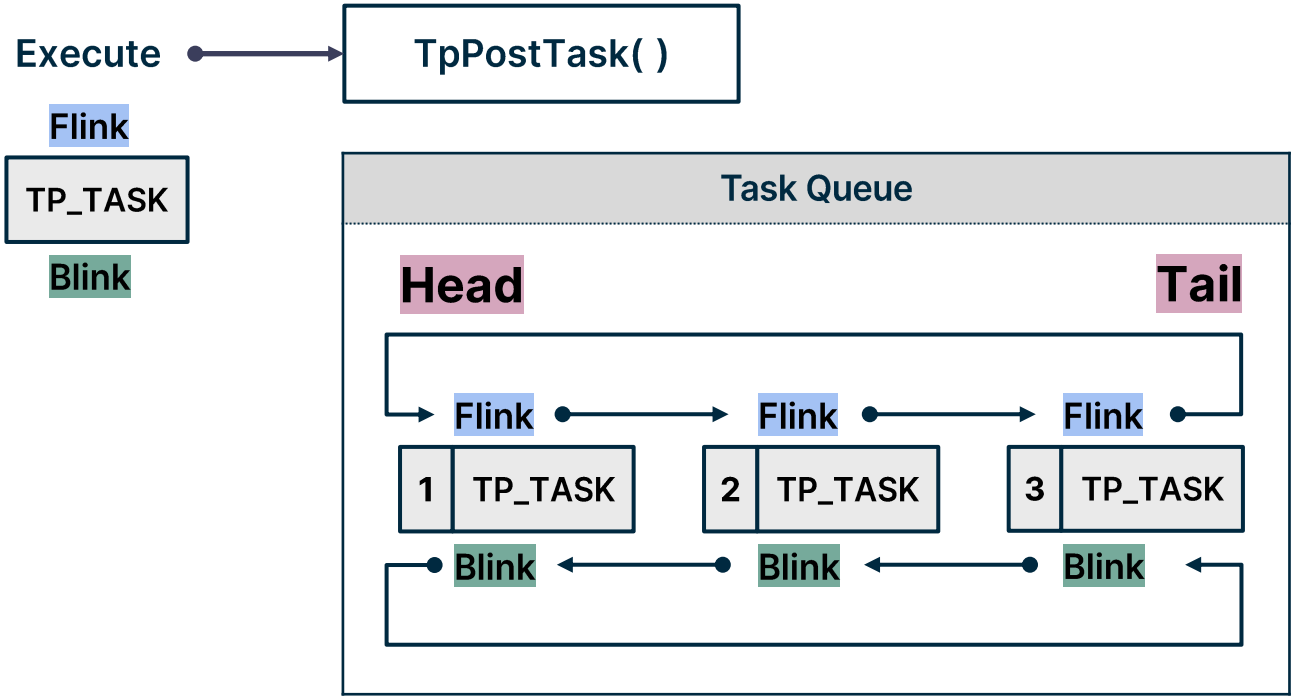
```
NTSTATUS NTAPI TpPostTask(TP_TASK* TpTask, TP_POOL* TpPool, int CallbackPriority, …)
{
    [snip]

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

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

    [snip]
}
```

Attacking Thread Pools - TP_WORK



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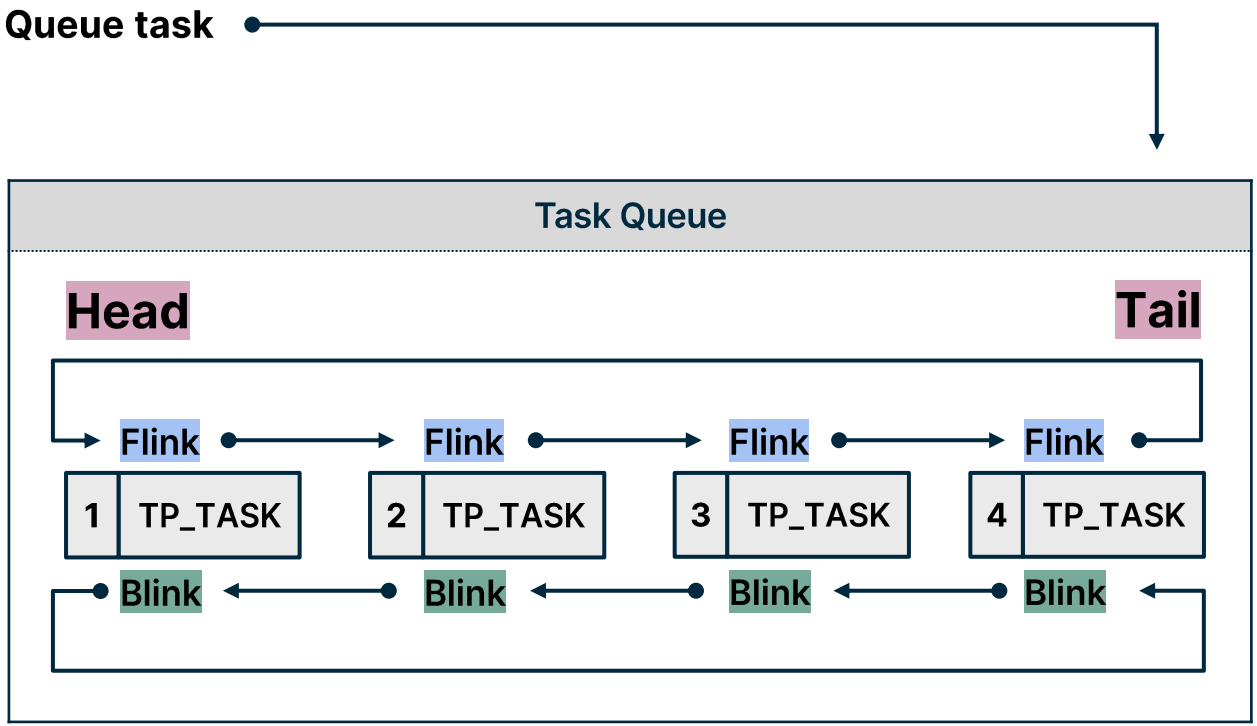

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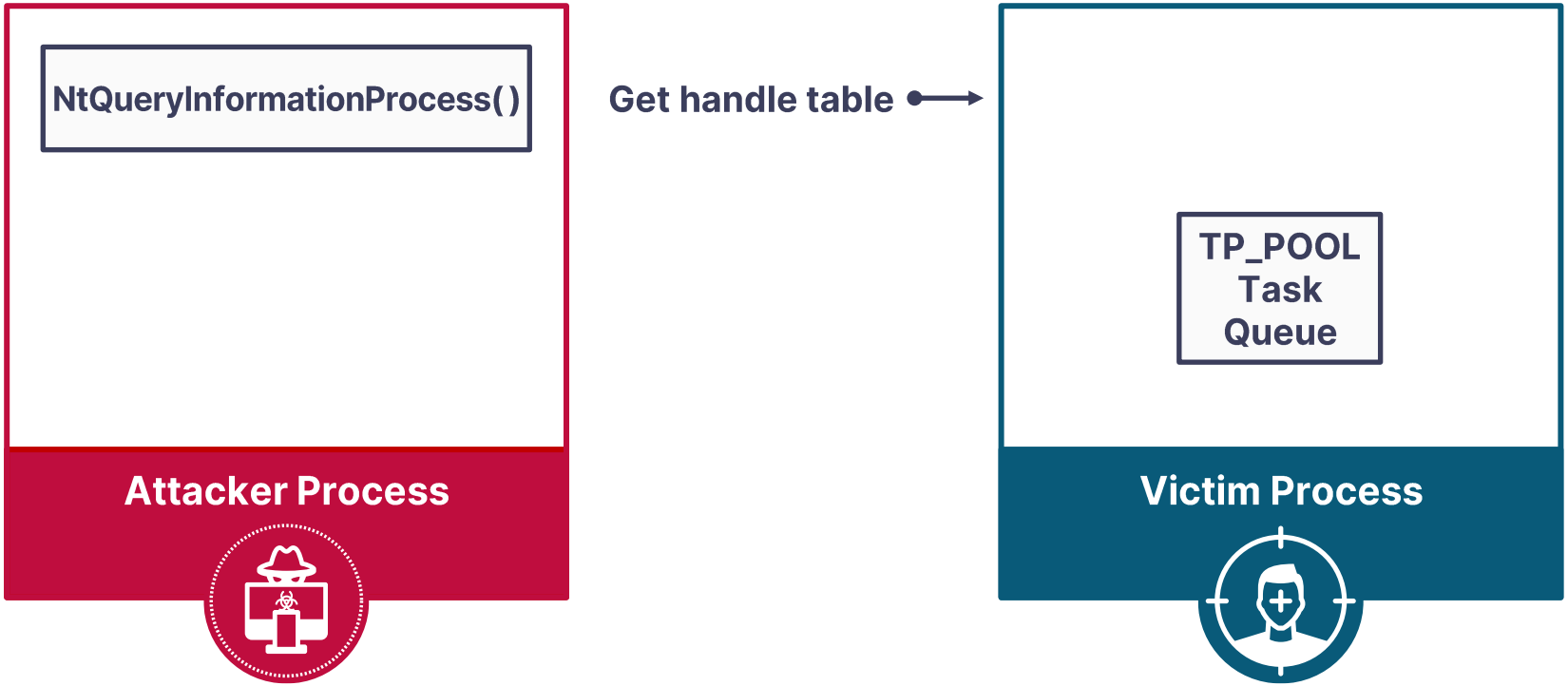

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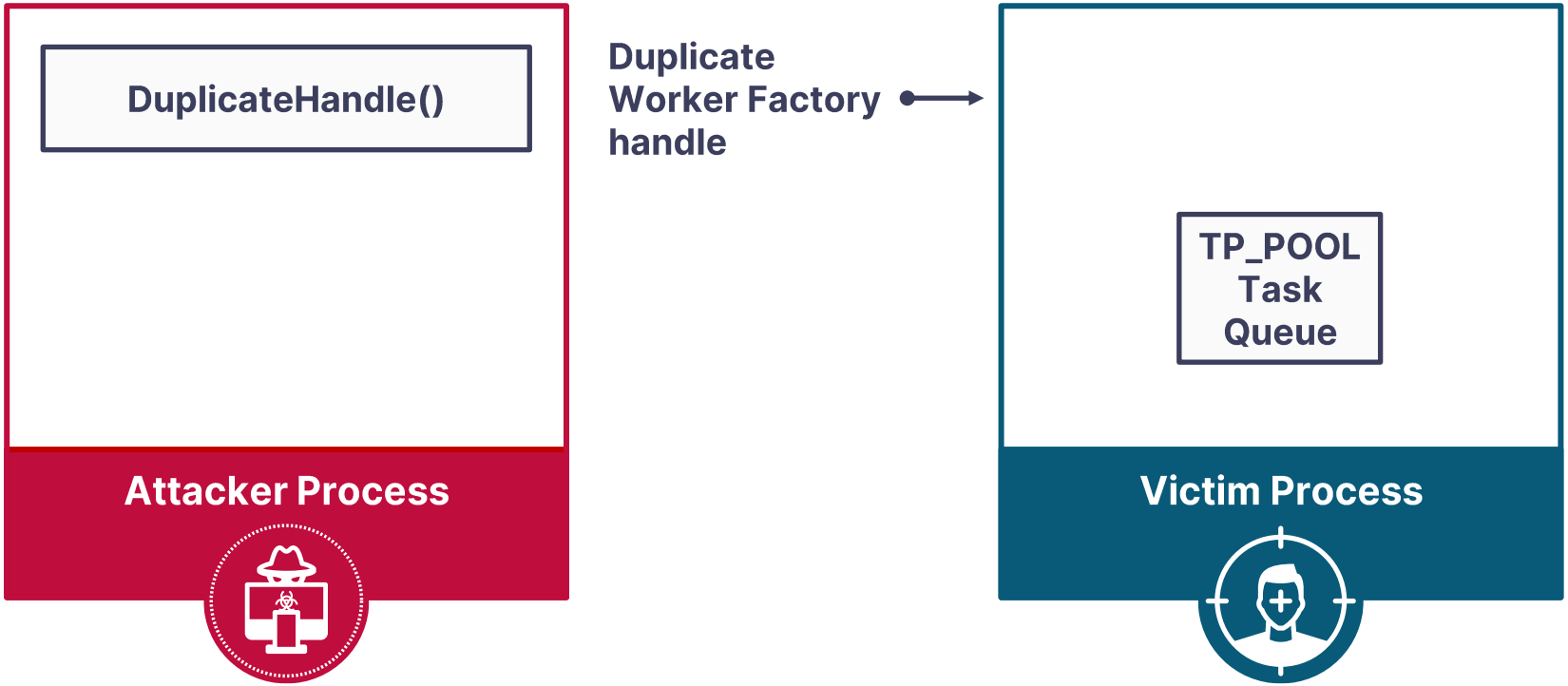

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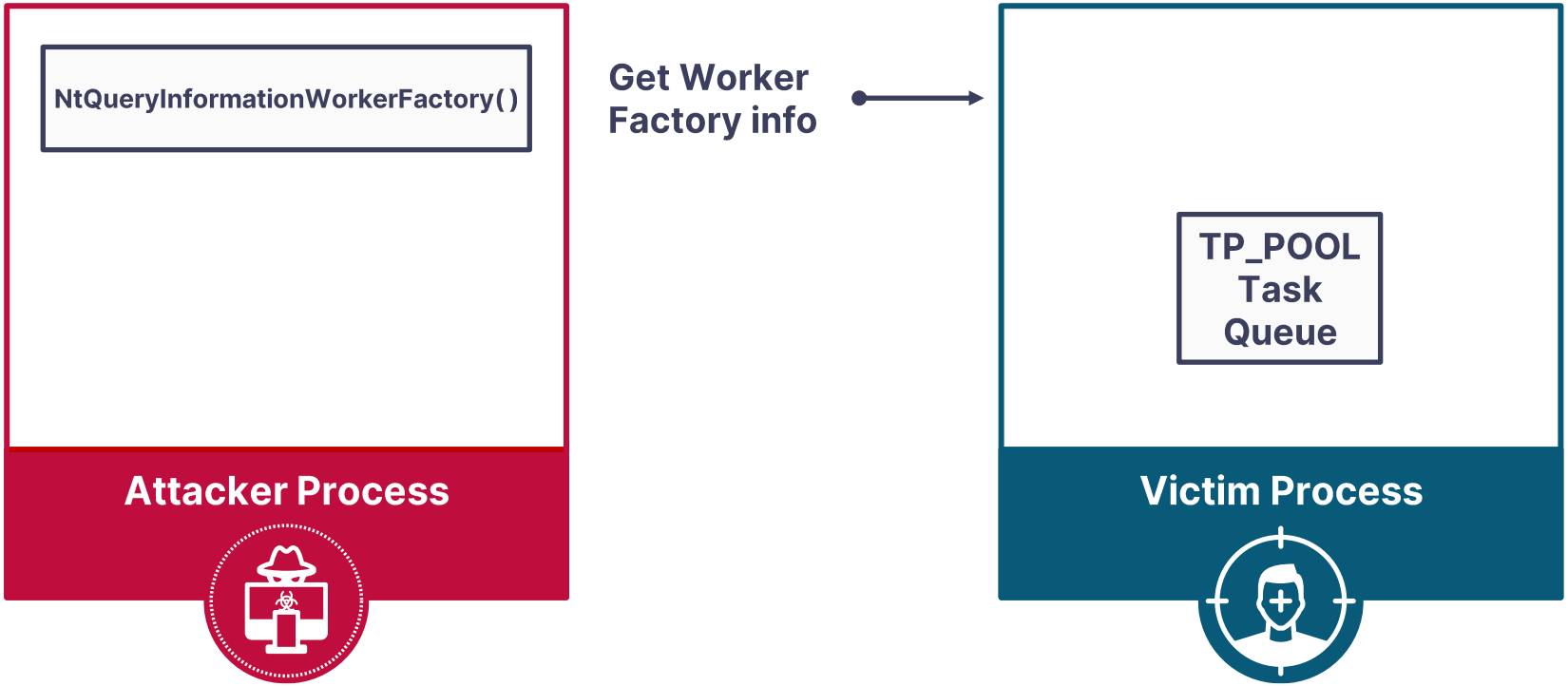

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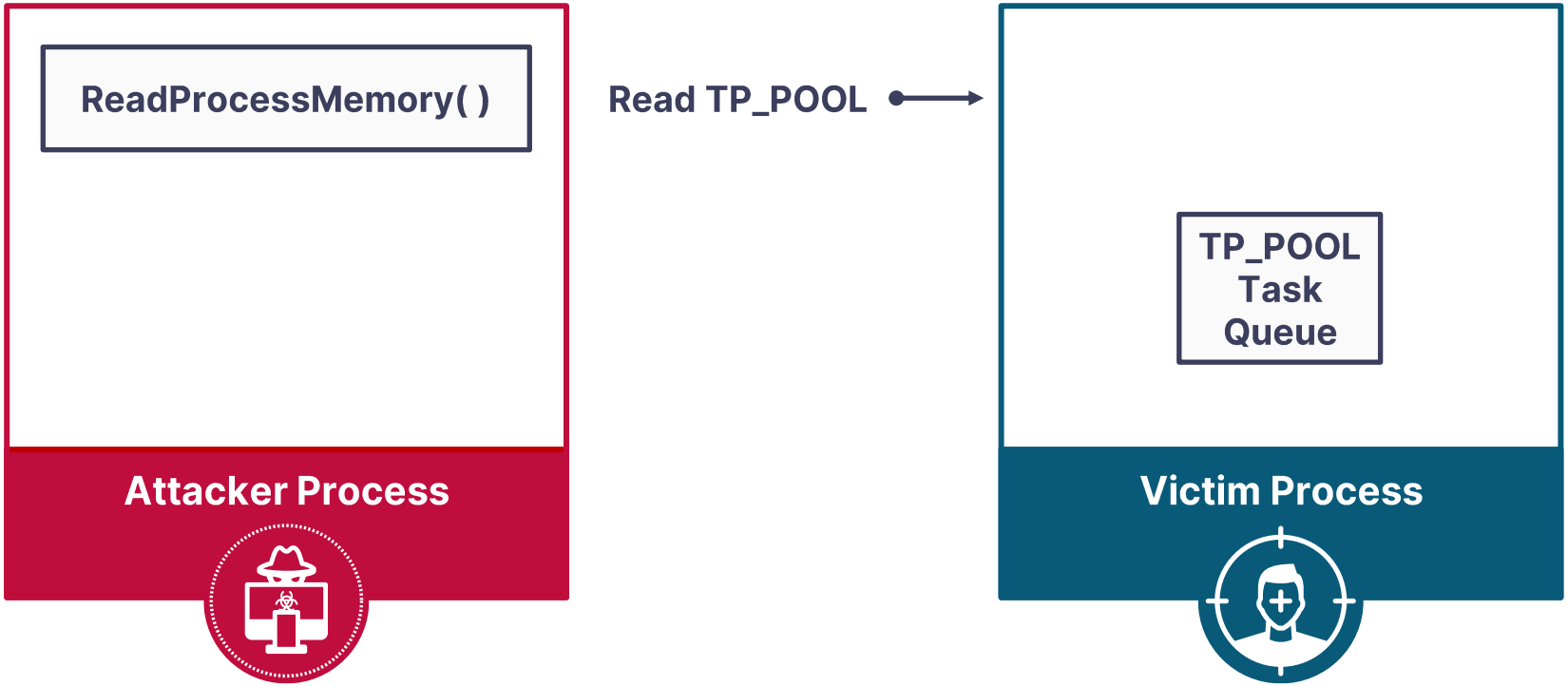

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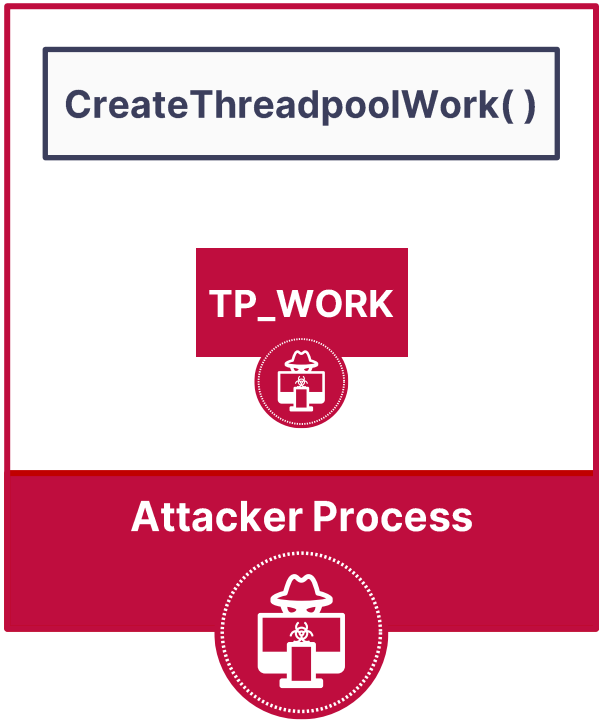

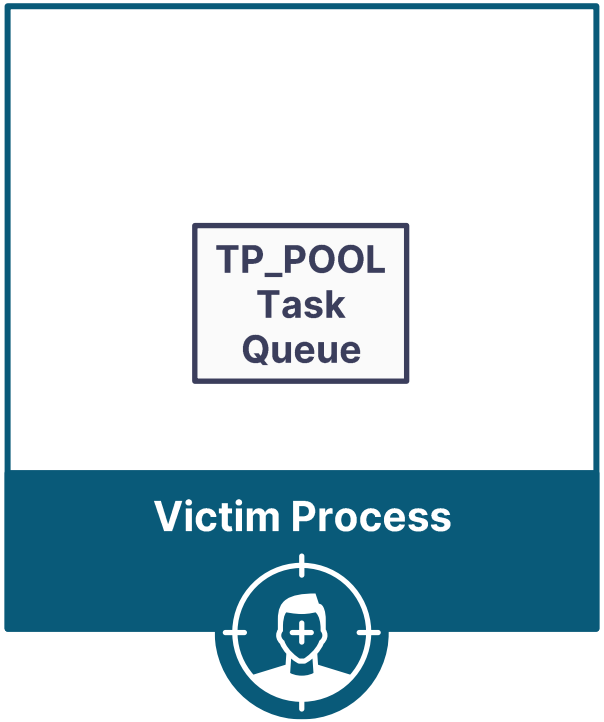

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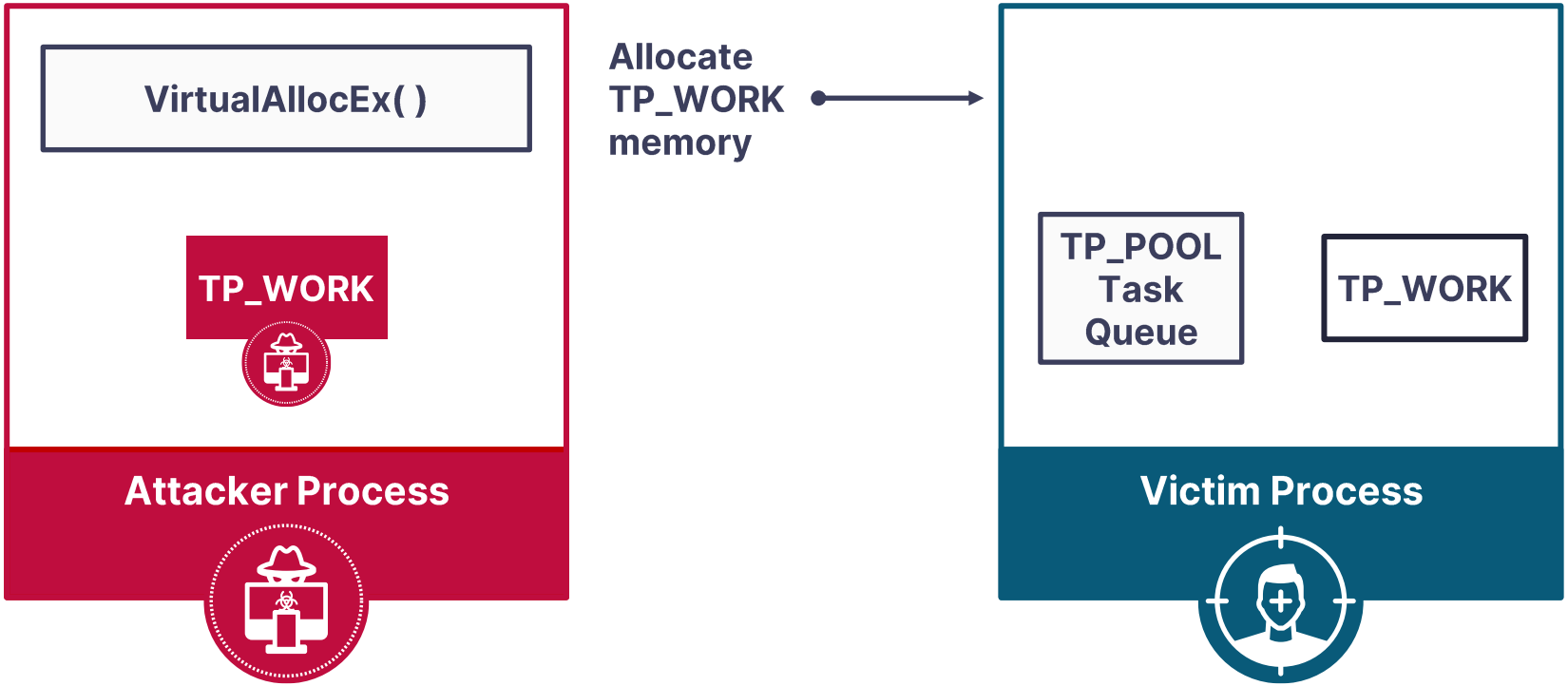

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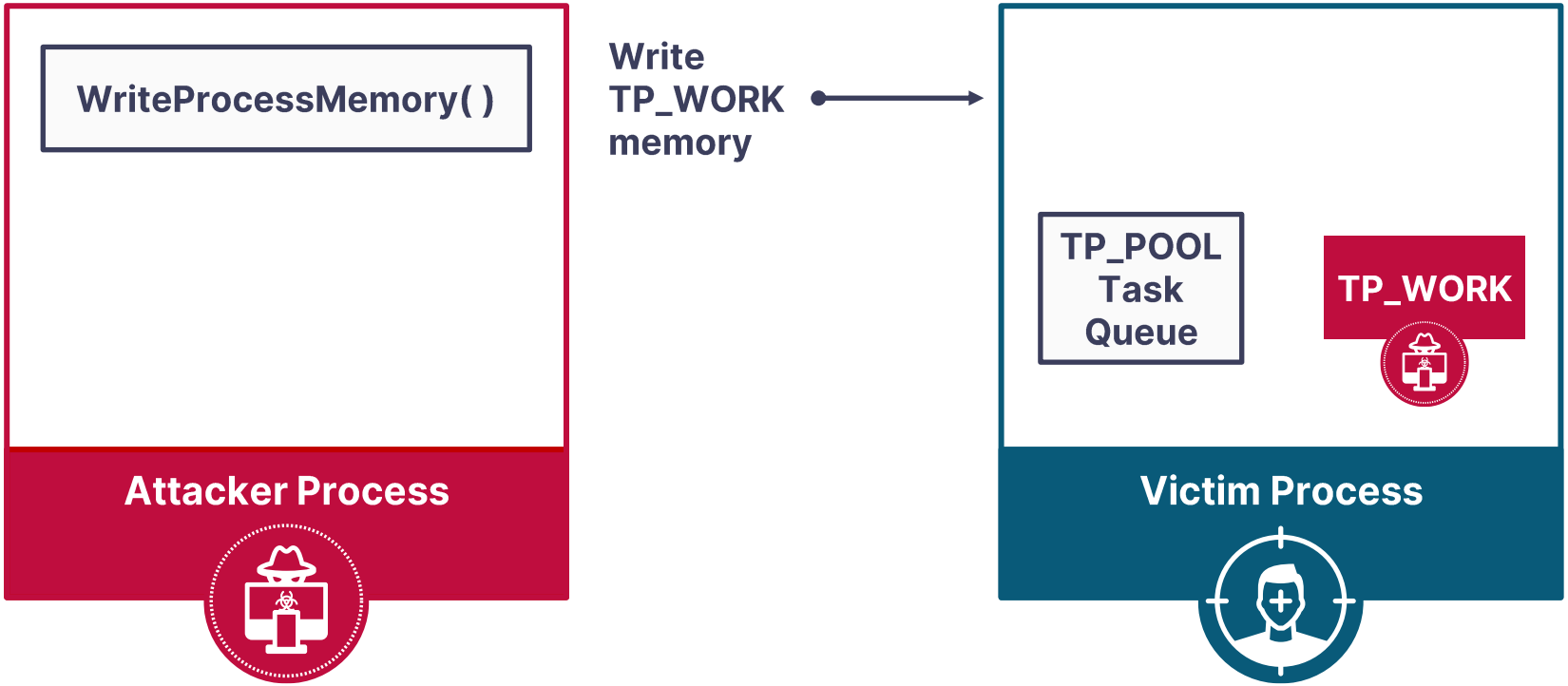

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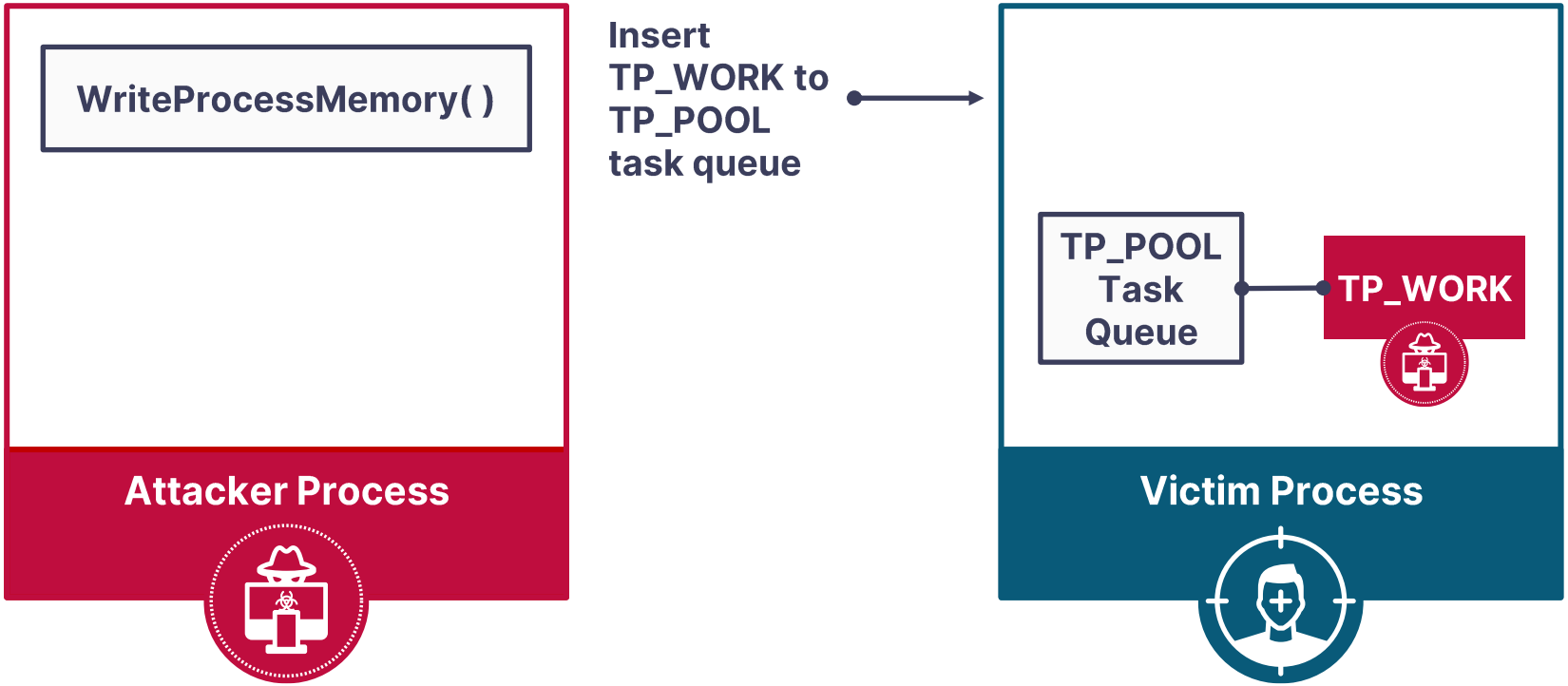


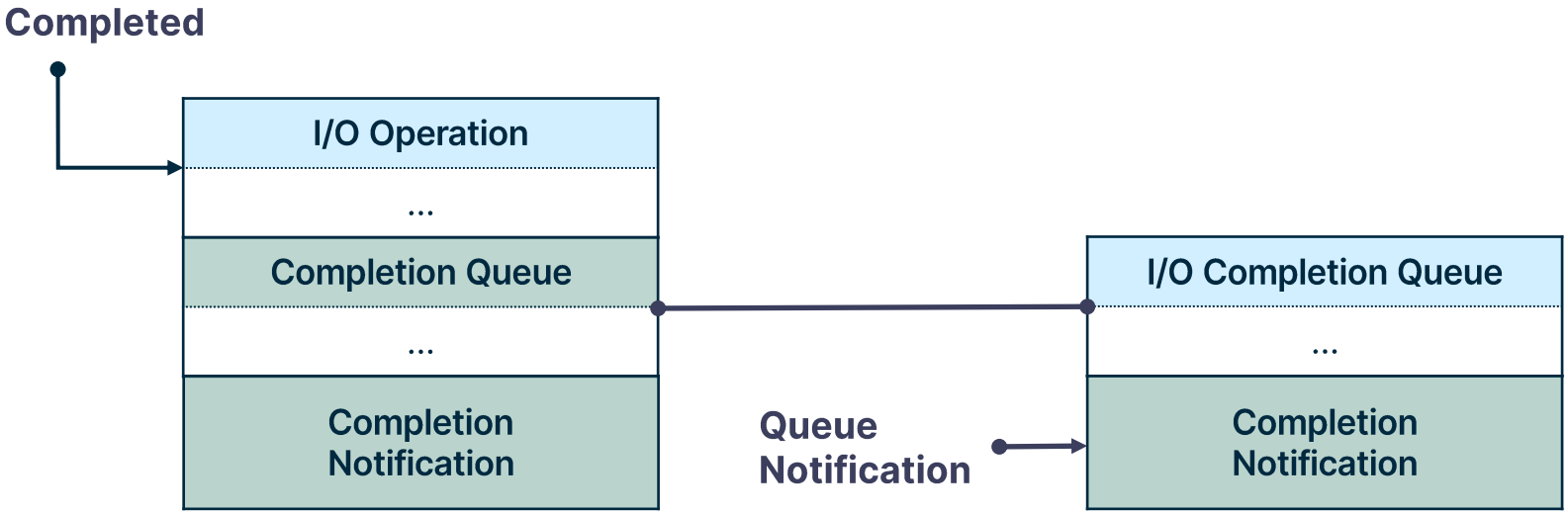
PoolParty State

Second friend in the pool

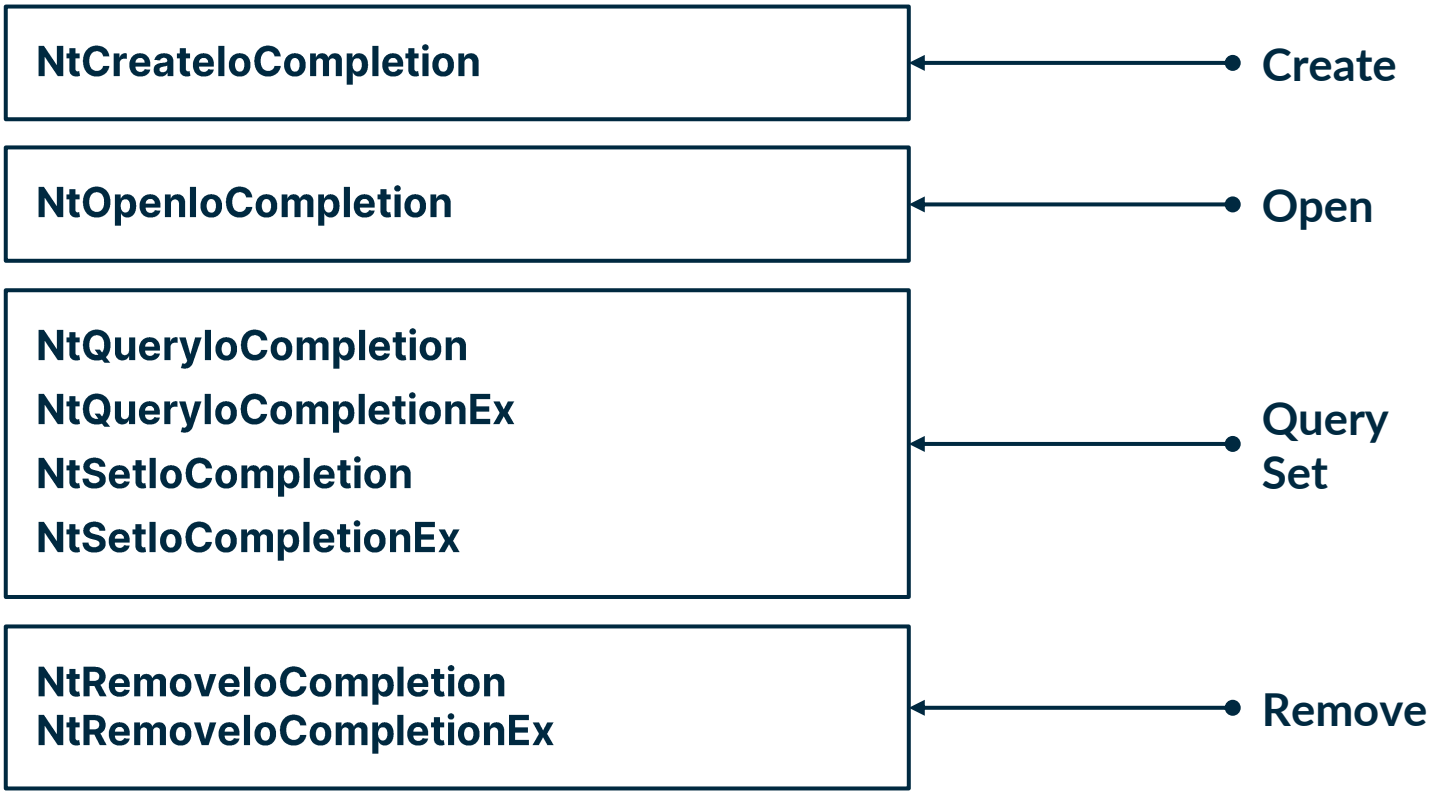
Attacking Thread Pools

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

I/O Completion Queues 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

Ntdll:: TpBindFileToDirect

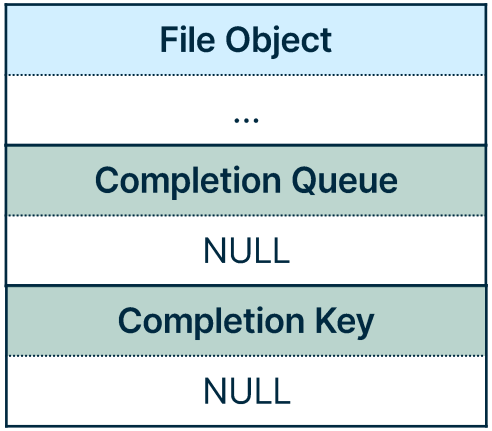
```
NTSTATUS NTAPI TpBindFileToDirect(HANDLE hFile, TP_DIRECT* TpDirect, TP_POOL* TpPool)
{
   [snip]

   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



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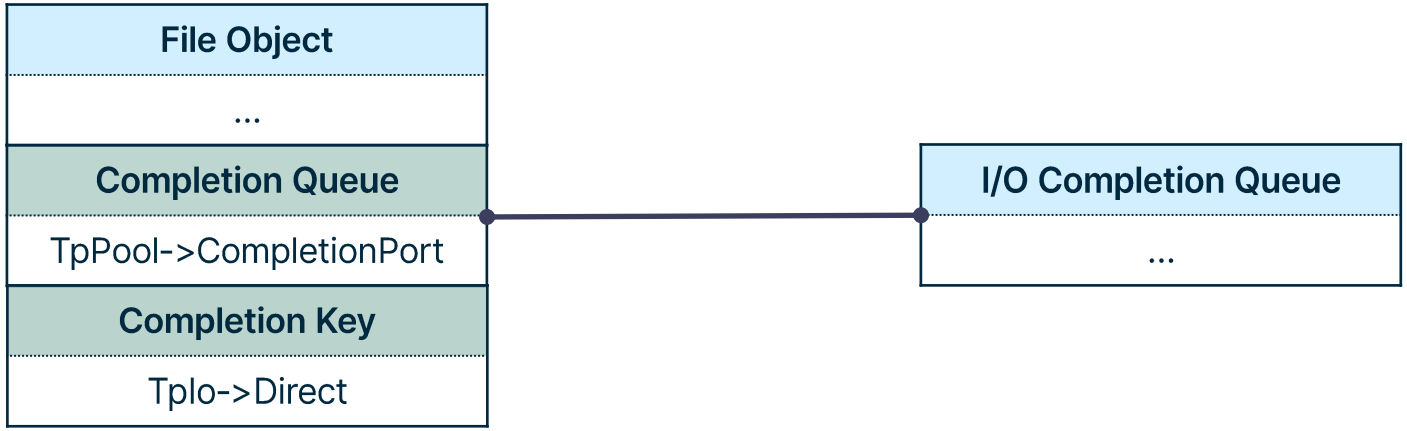

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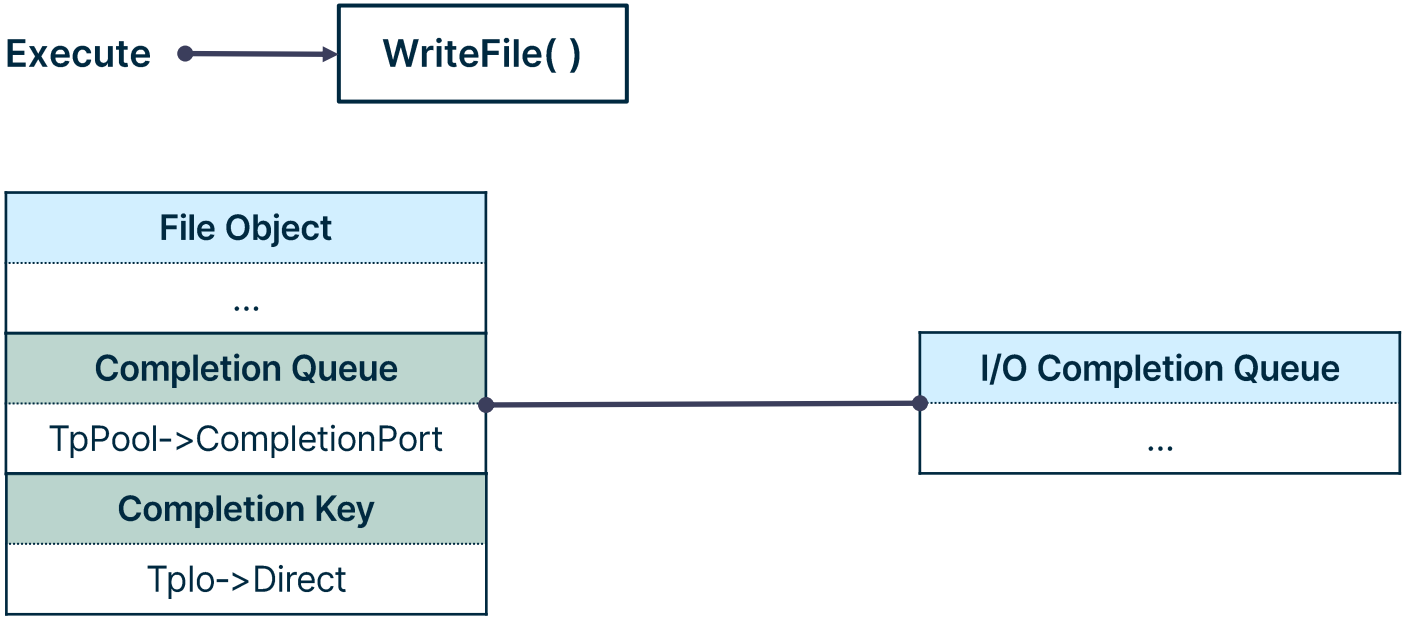

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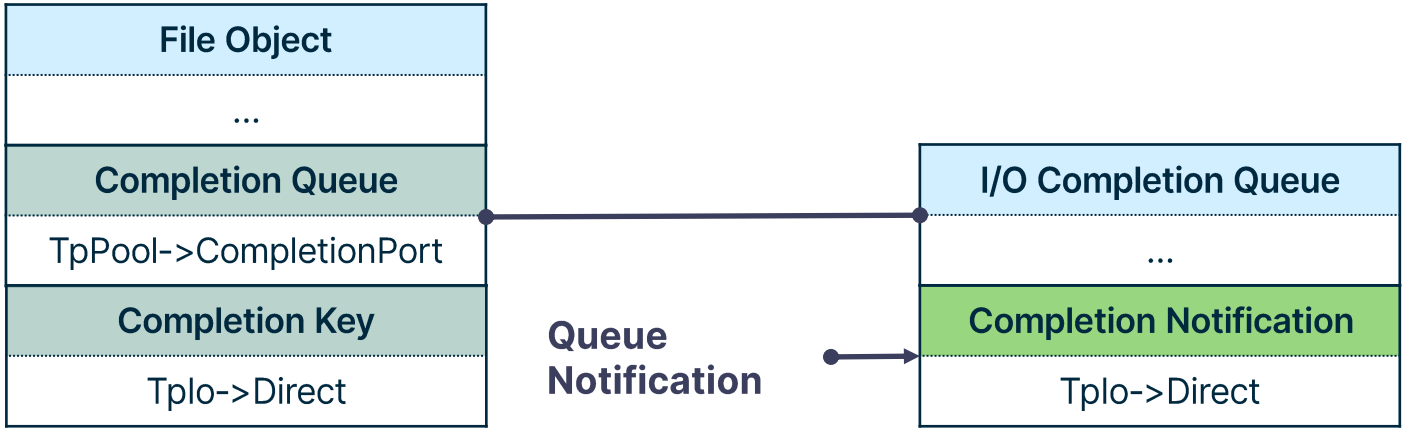
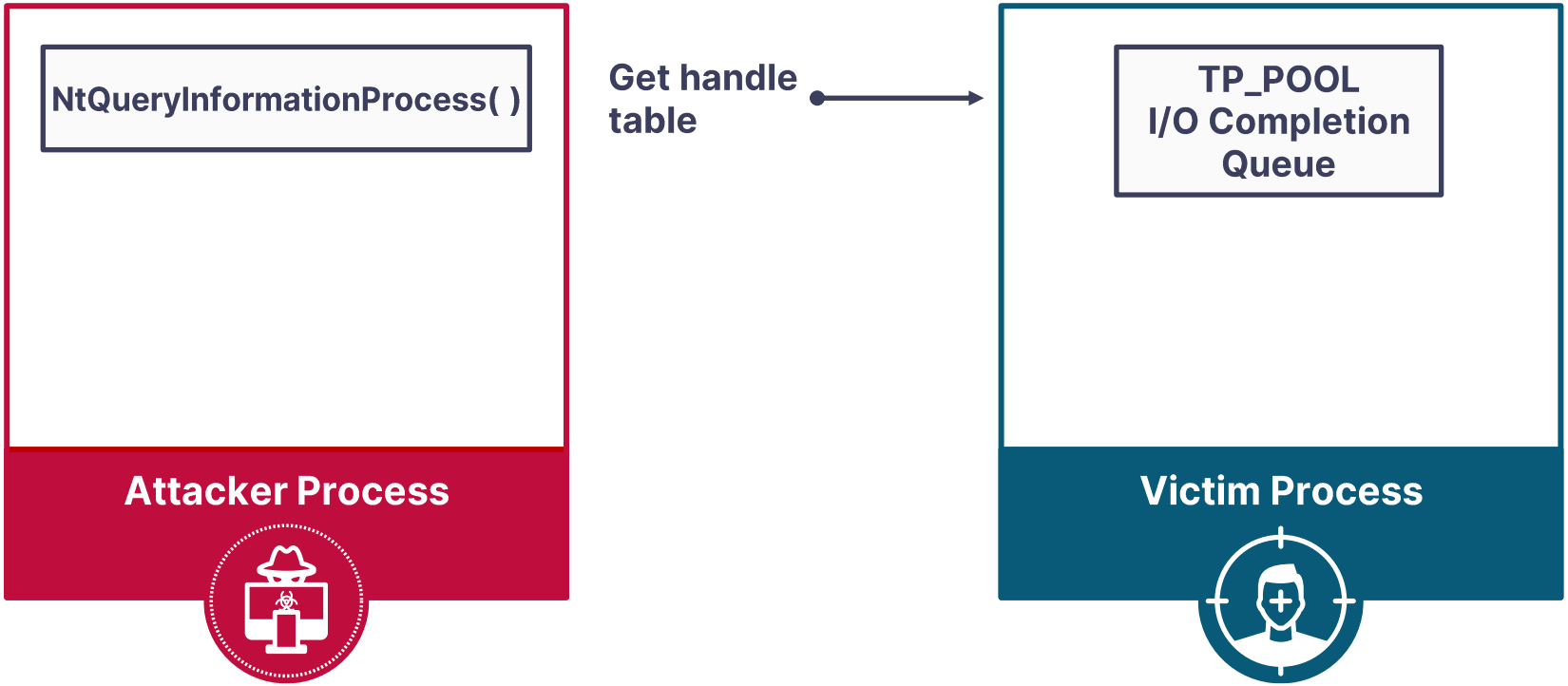


Attacking Thread Pools - TP_IO



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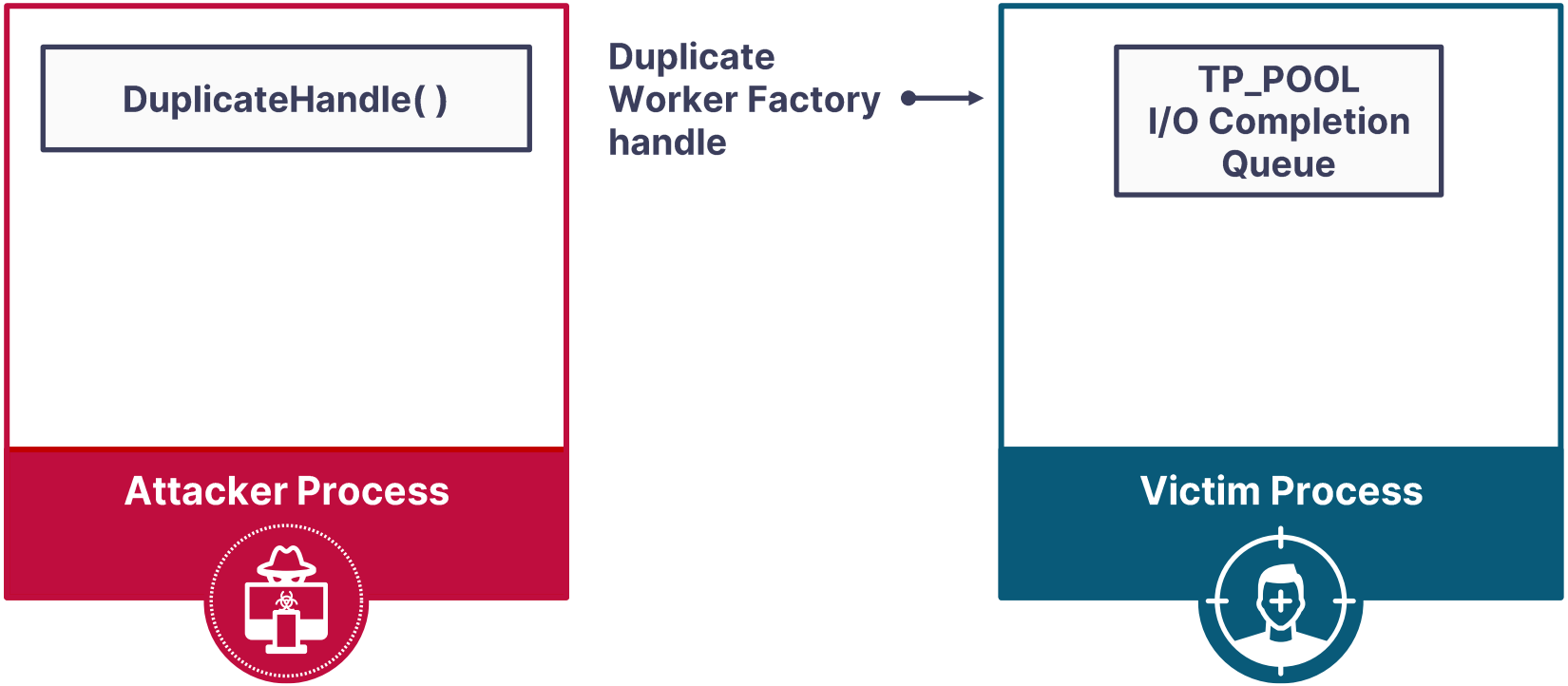

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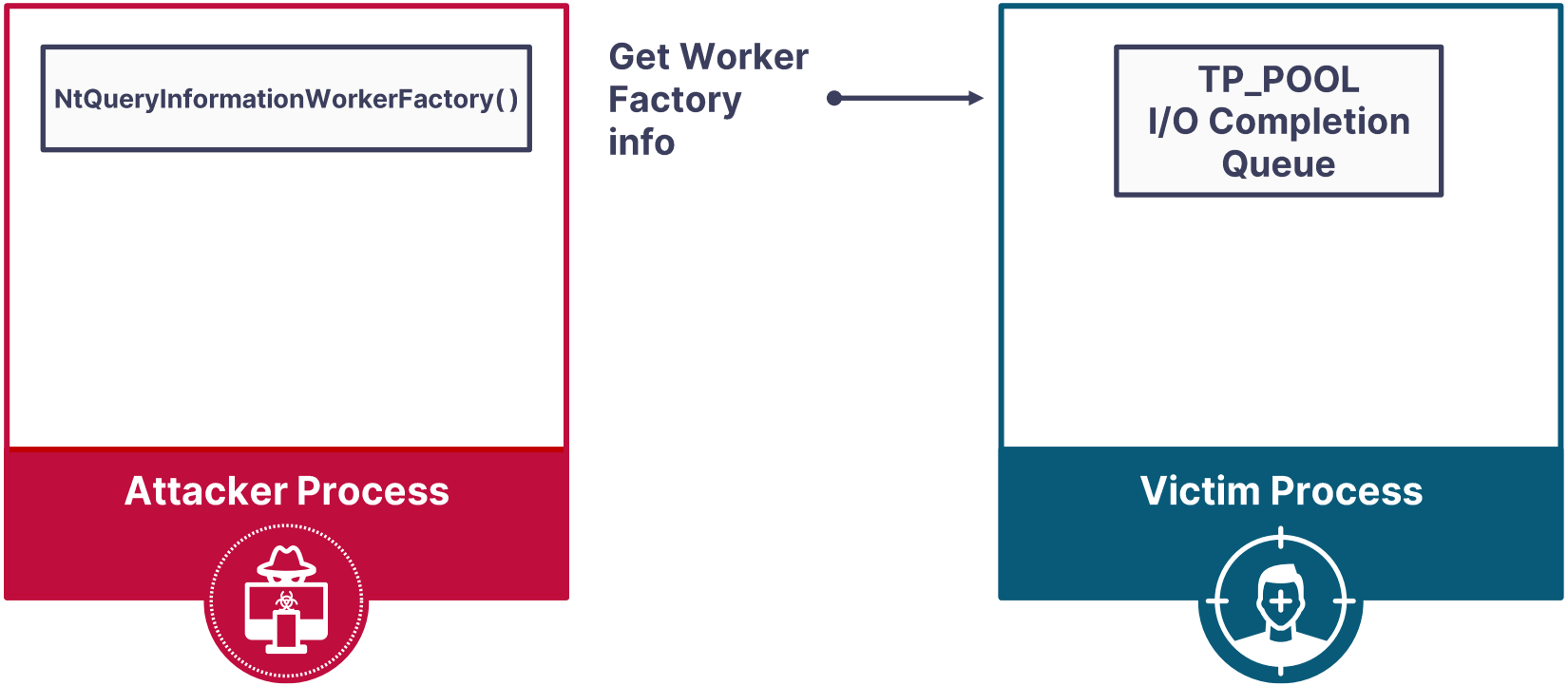

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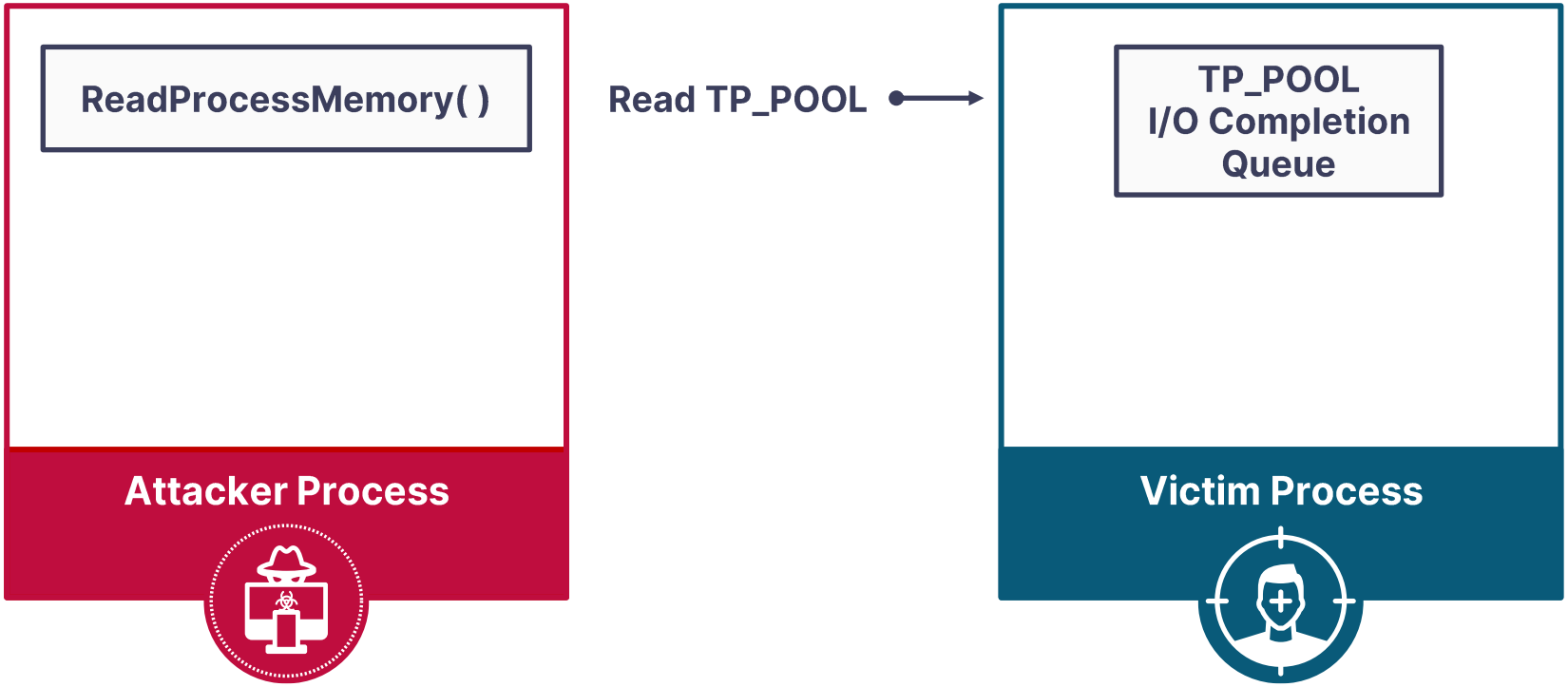

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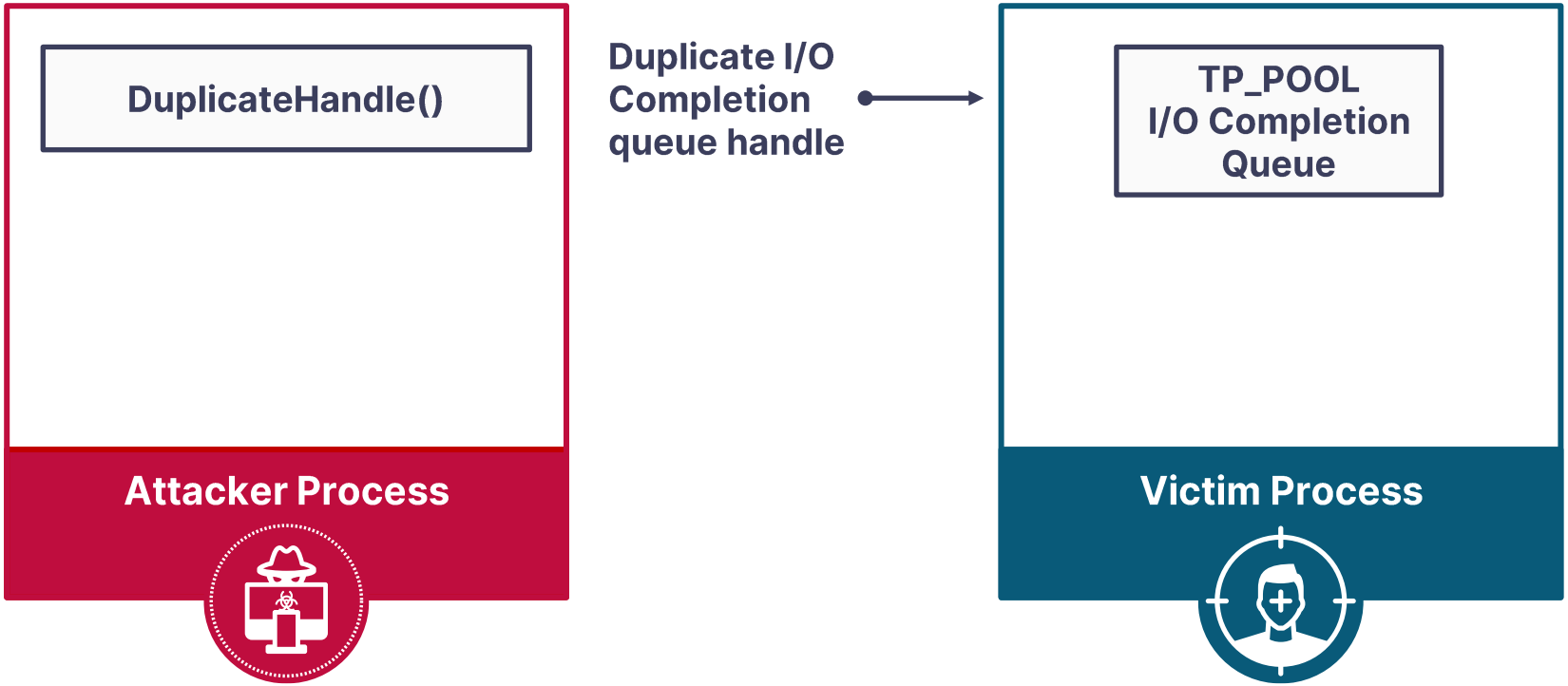

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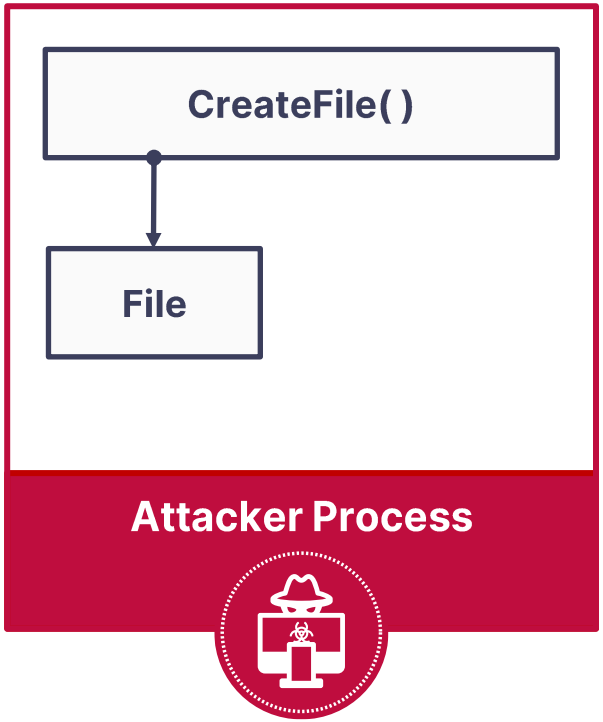
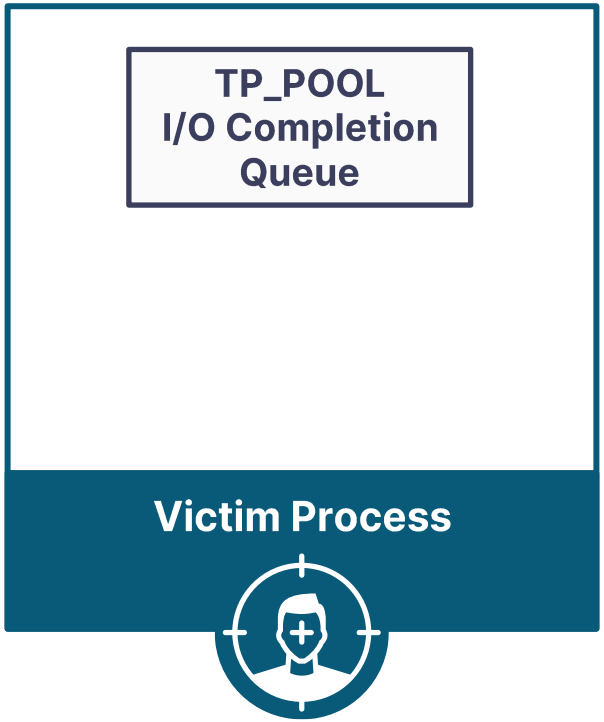
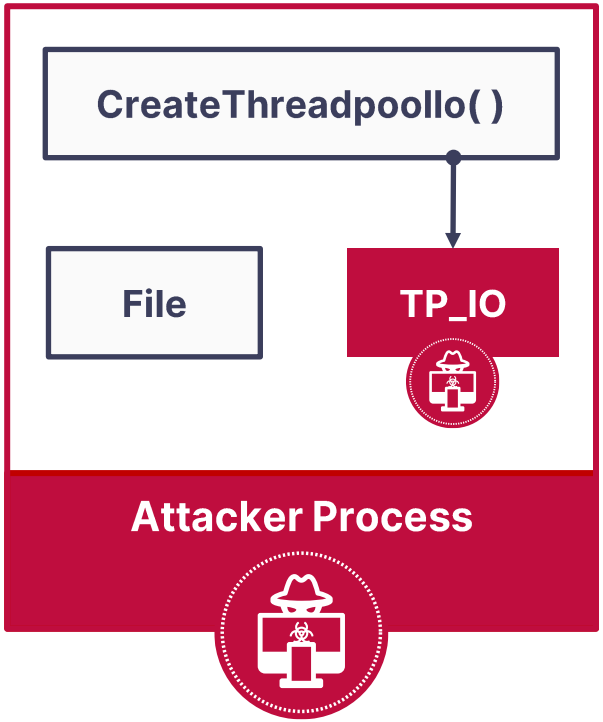
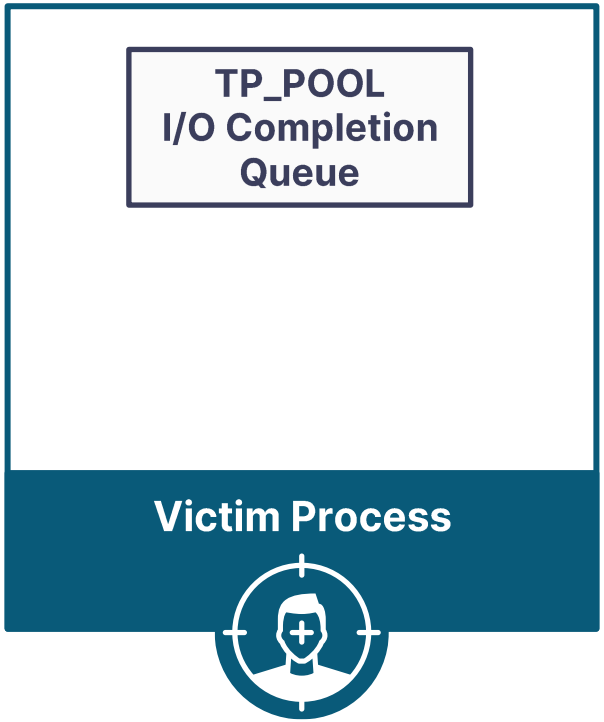


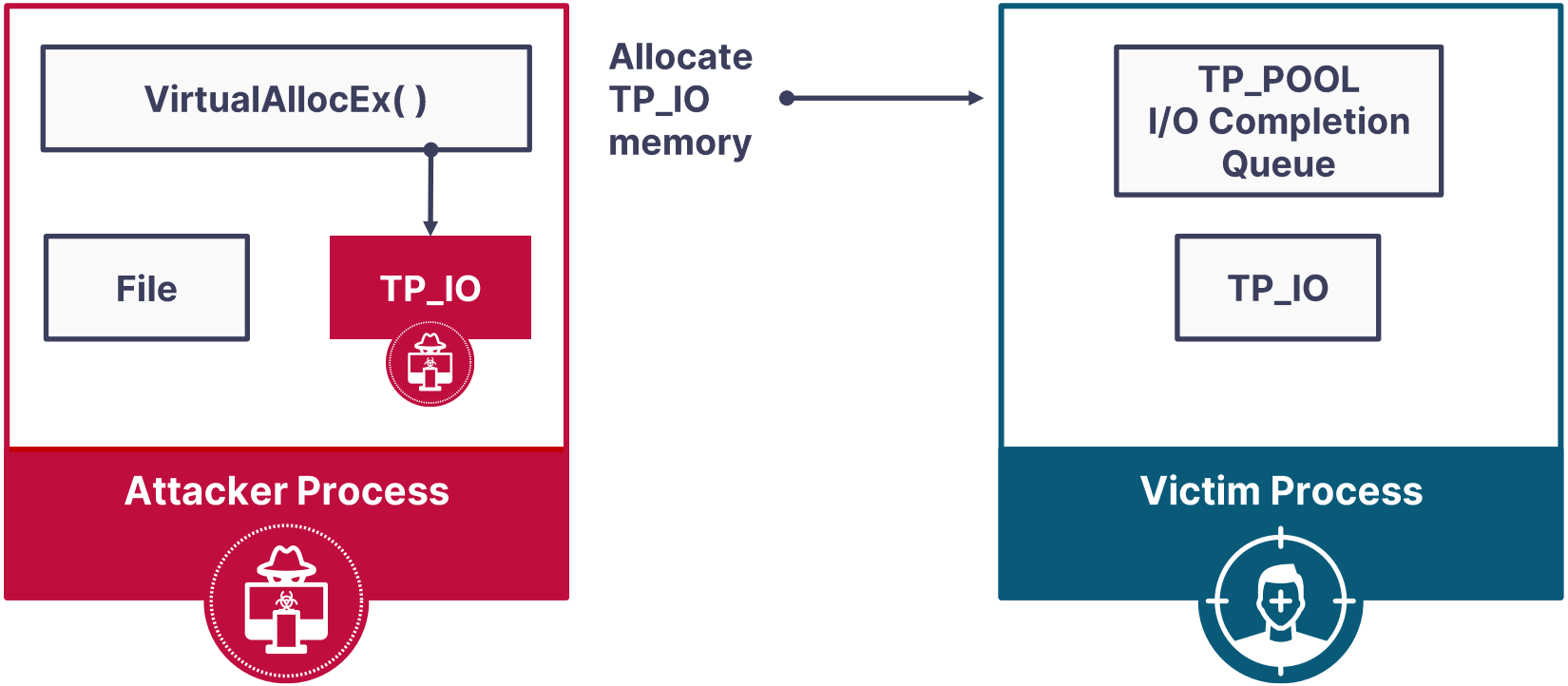


Attacking Thread Pools - TP_IO





Attacking Thread Pools - TP_IO



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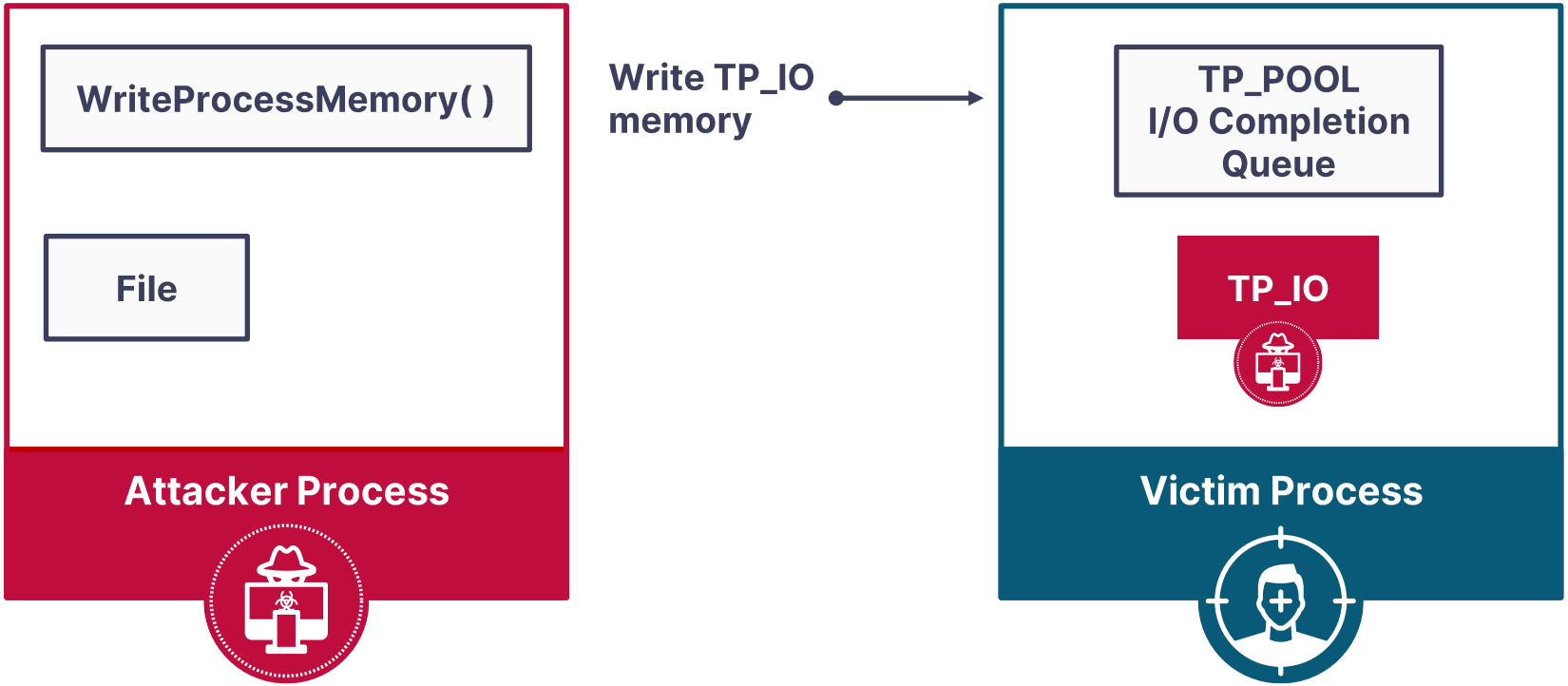
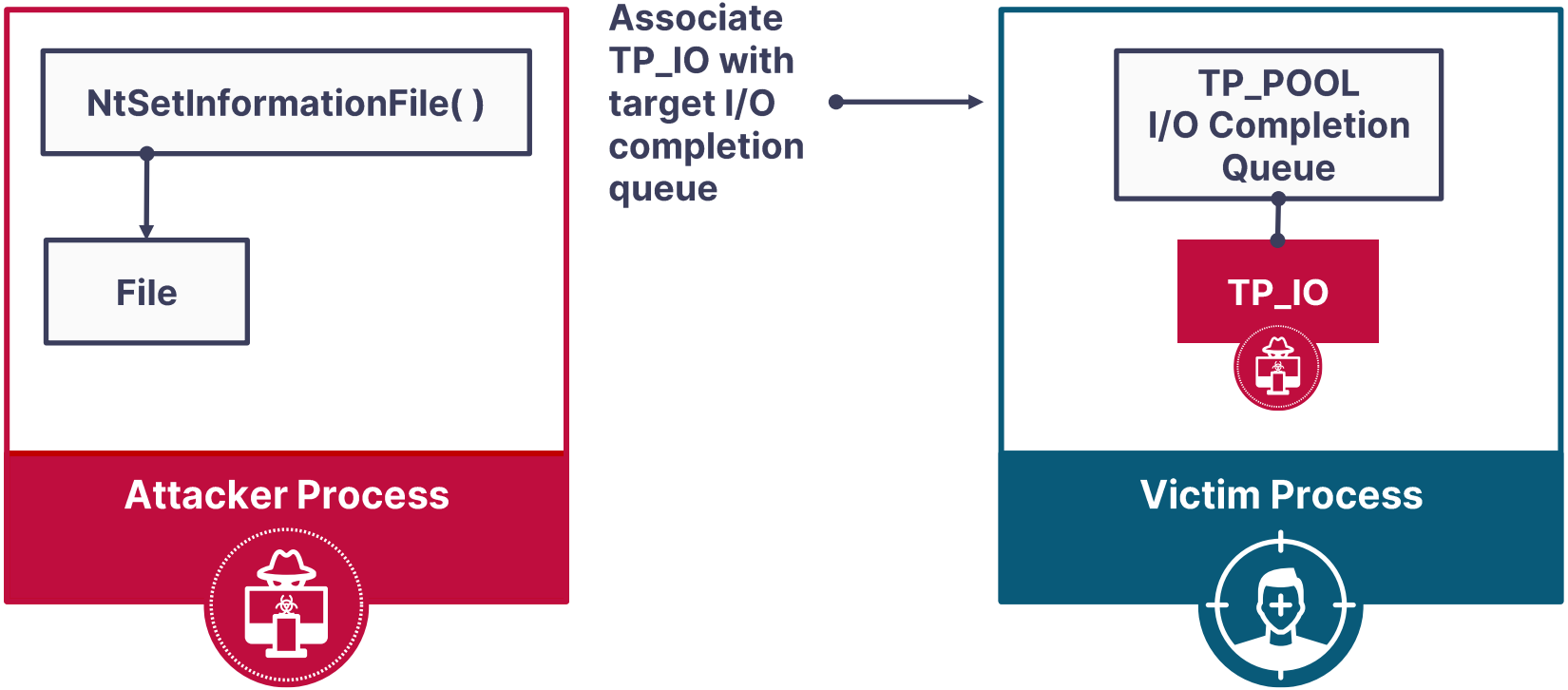
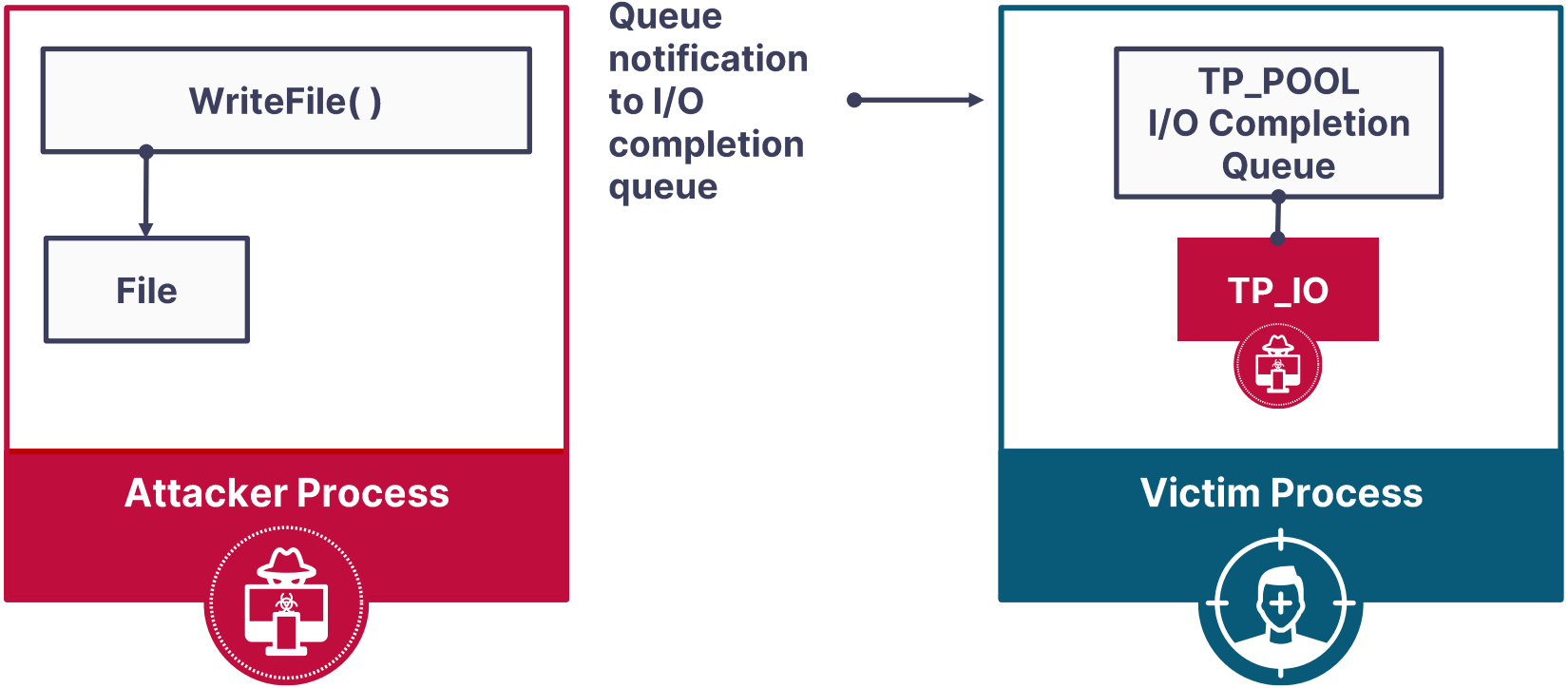


Attacking Thread Pools - TP_IO



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	

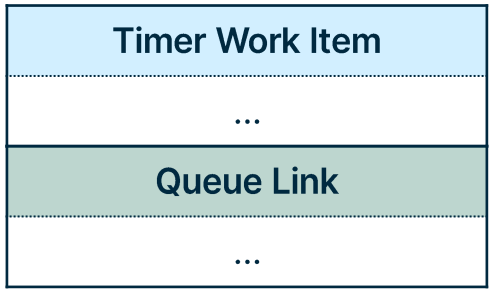
Attacking Thread Pools - TP_TIMER

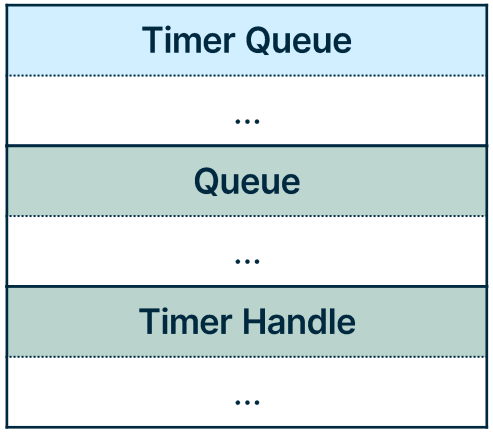
No timer handle is supplied

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

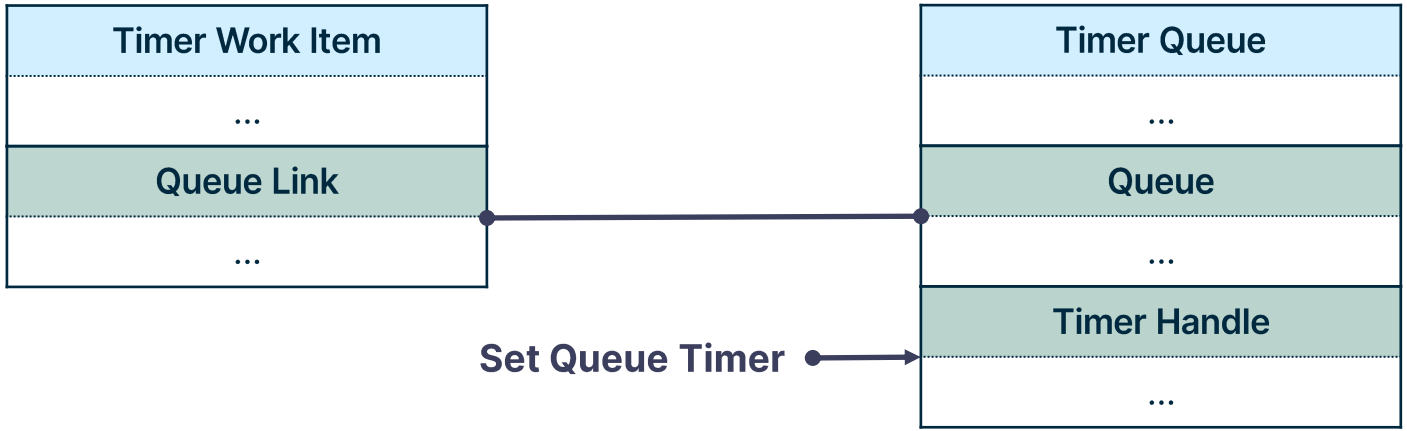
```
void NTAPI SetThreadpoolTimer(
    _In_     PTP_TIMER_CALLBACK TimerCallback,
    _In_Opt  PFILETIME DueTime,
    _In_     DWORD Period,
    _In_     DWORD WindowLength
);
```

Attacking Thread Pools – TP_TIMER

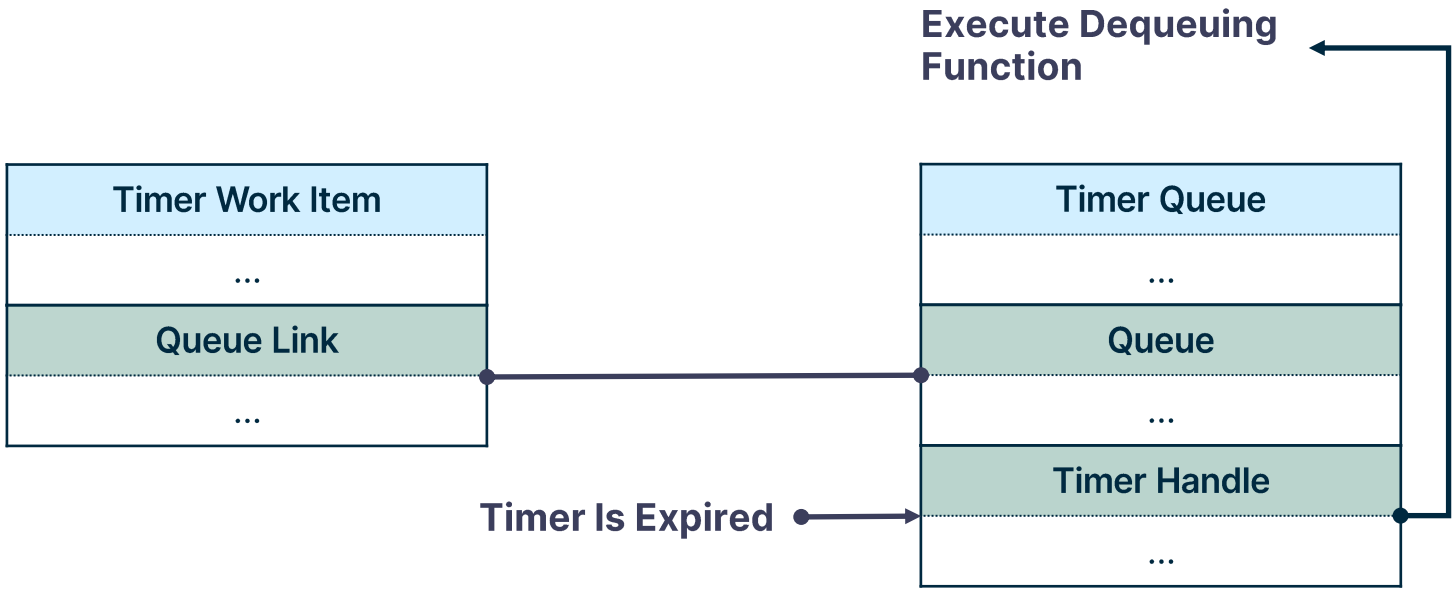




Attacking Thread Pools – TP_TIMER



Attacking Thread Pools – TP_TIMER



Attacking Thread Pools - TP_TIMER

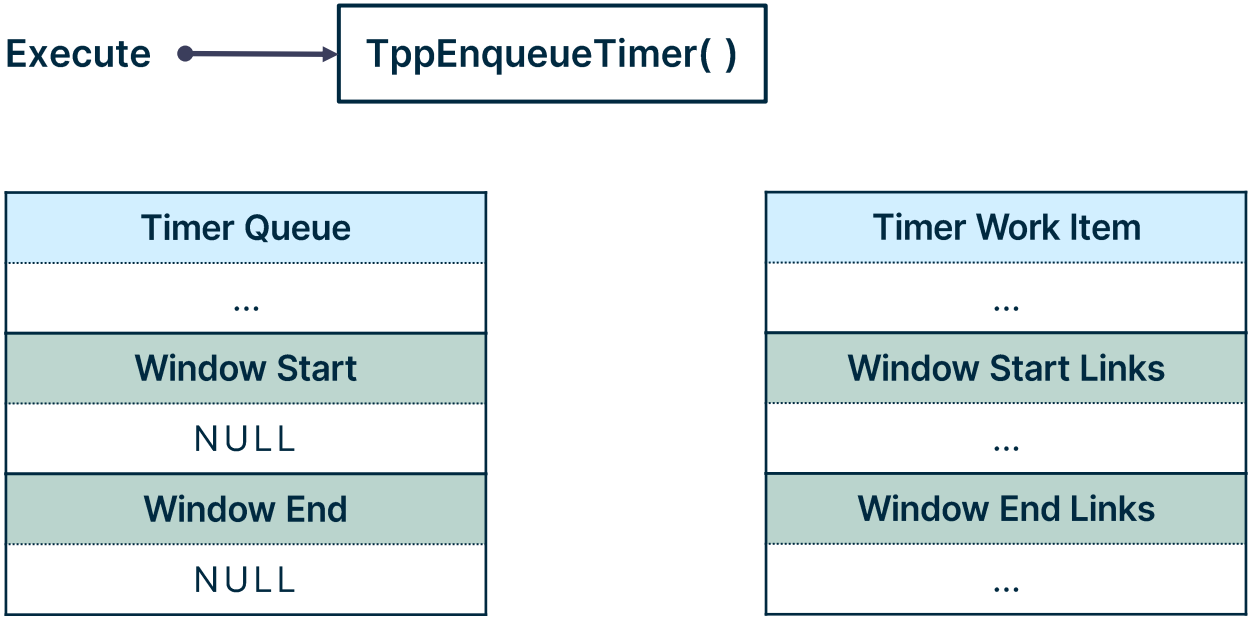
```
typedef struct _TP_TIMER
{
    [snip]
    TPP_PH_LINKS WindowEndLinks;
    TPP_PH_LINKS WindowStartLinks;
    [snip]
} TP_TIMER, * PTP_TIMER;
```

Attacking Thread Pools - TP_TIMER

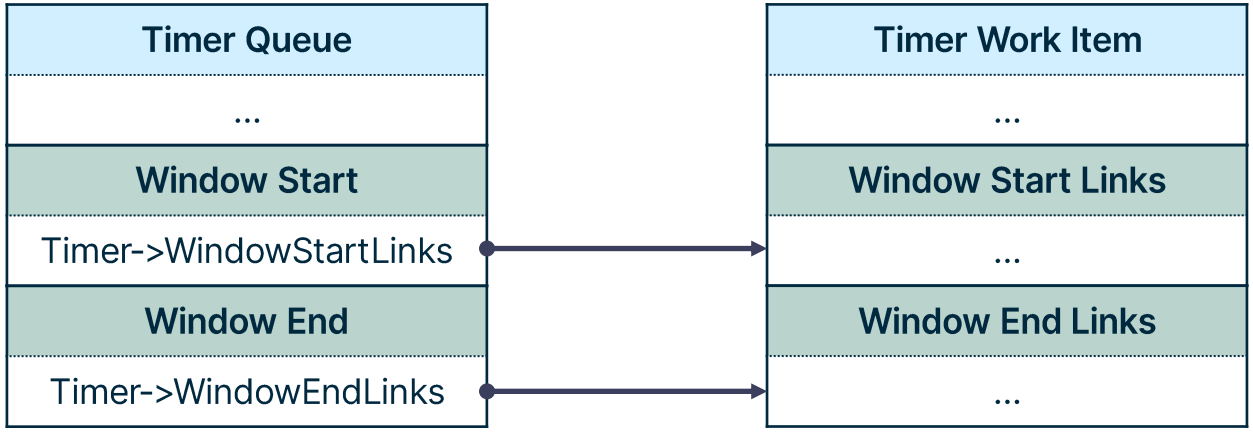
Ntdll:: TppEnqueueTimer

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

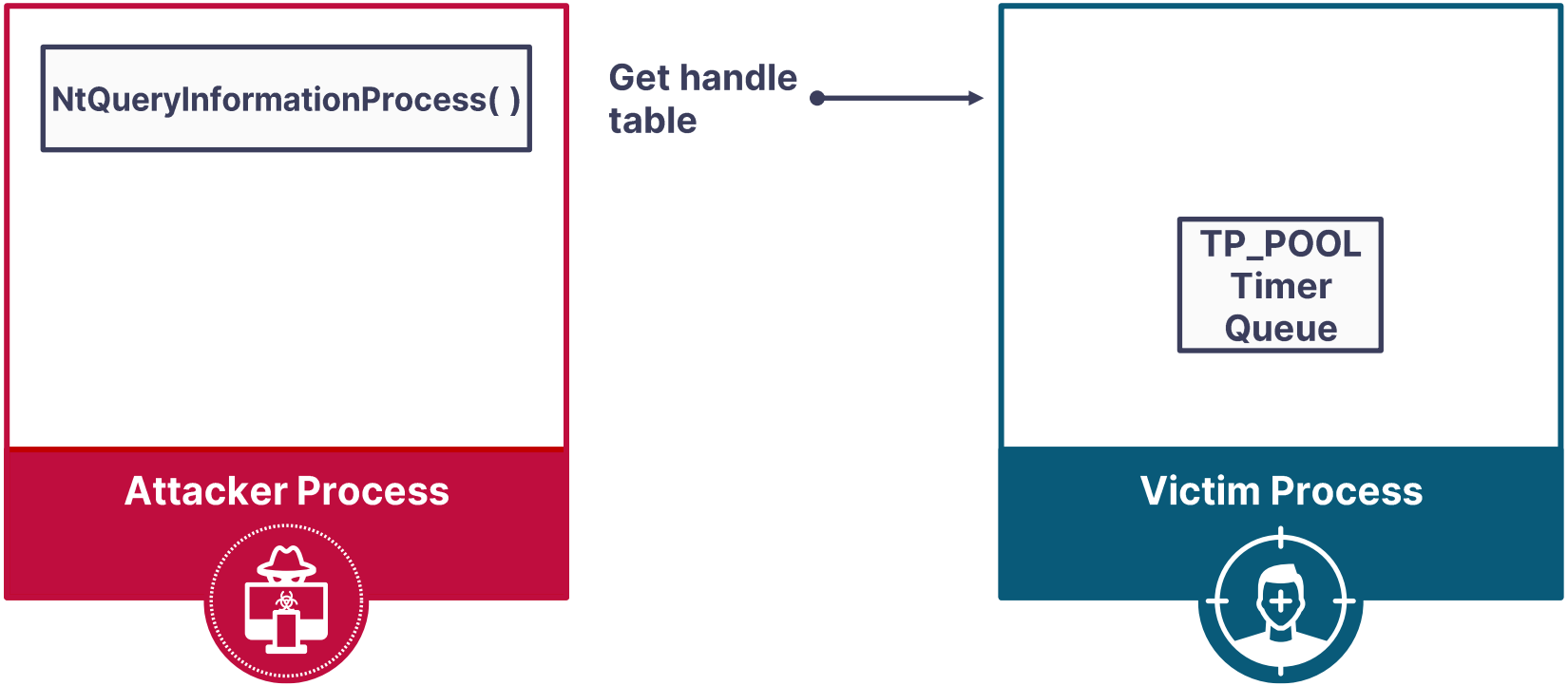
Attacking Thread Pools – TP_TIMER



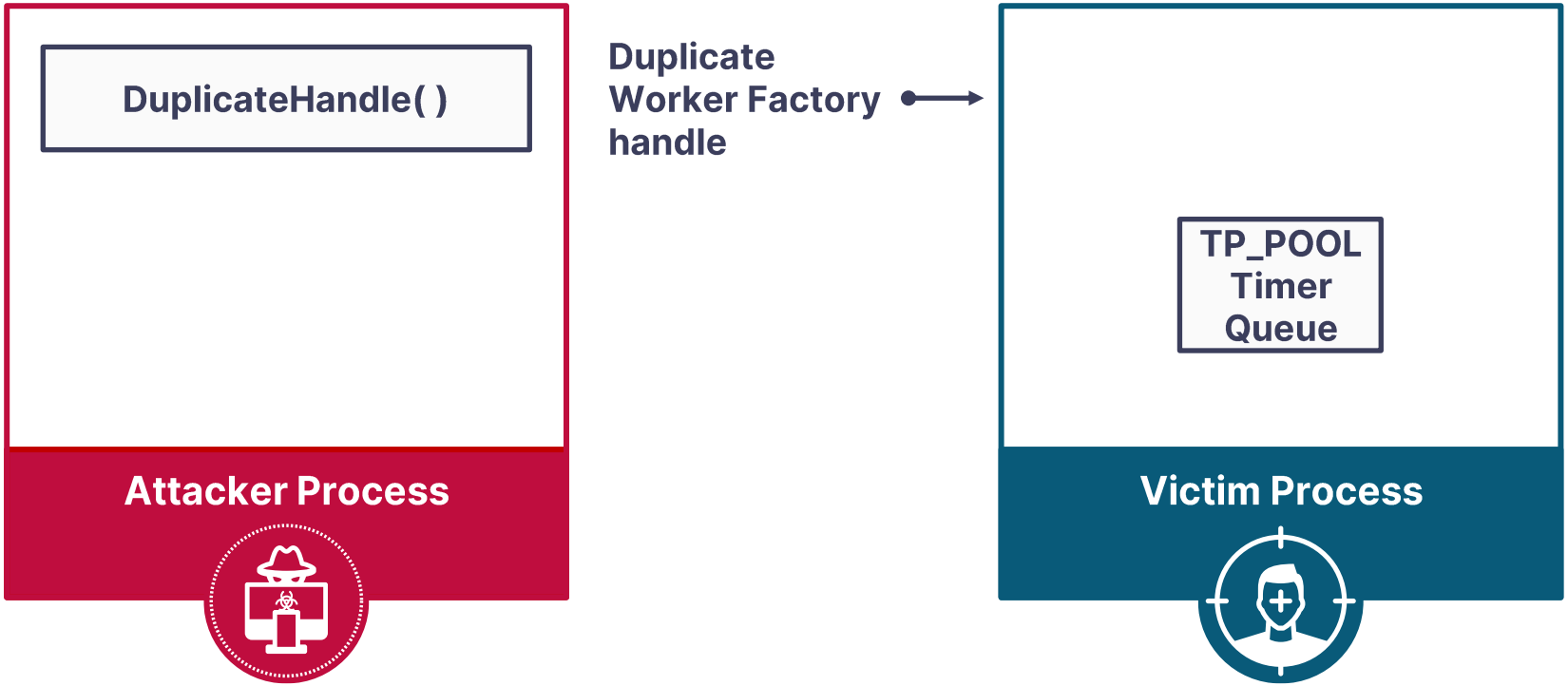
Attacking Thread Pools – TP_TIMER



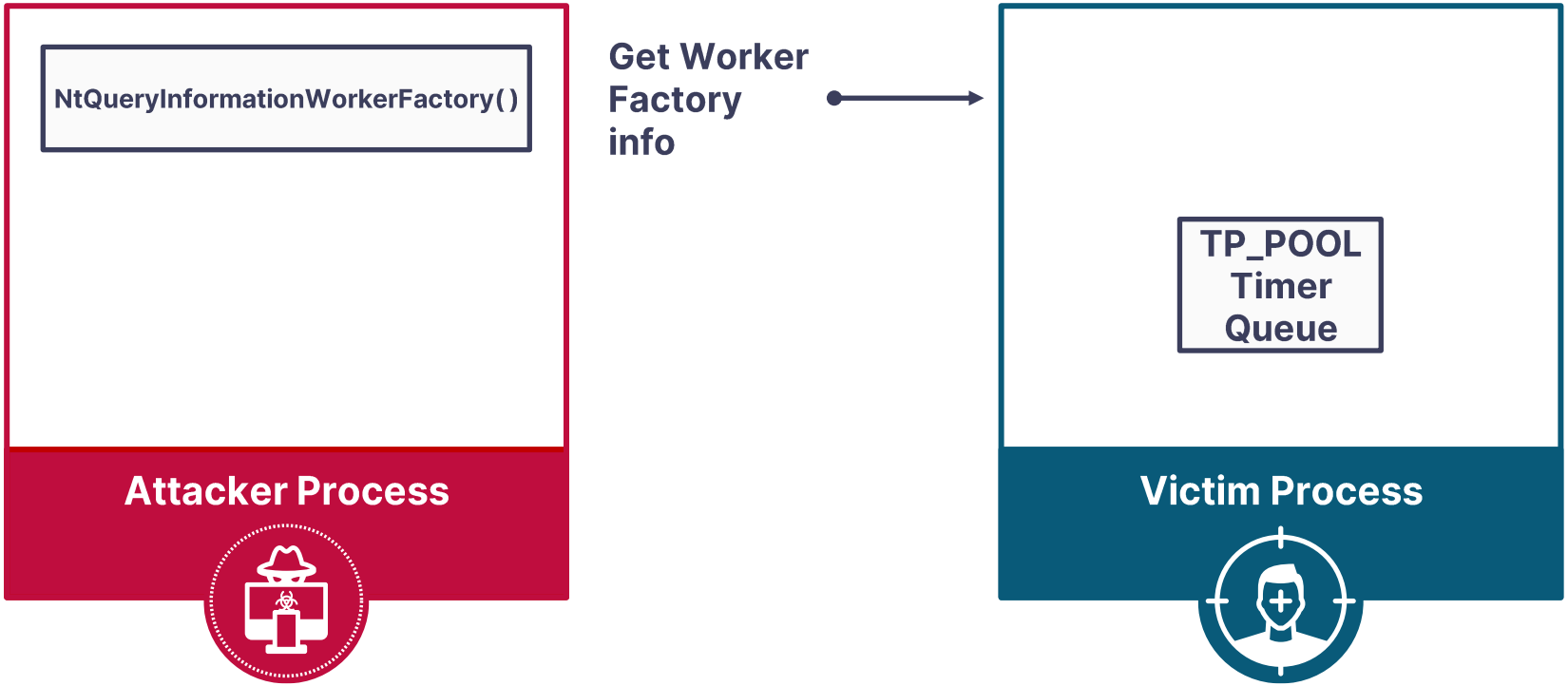
Attacking Thread Pools – TP_TIMER



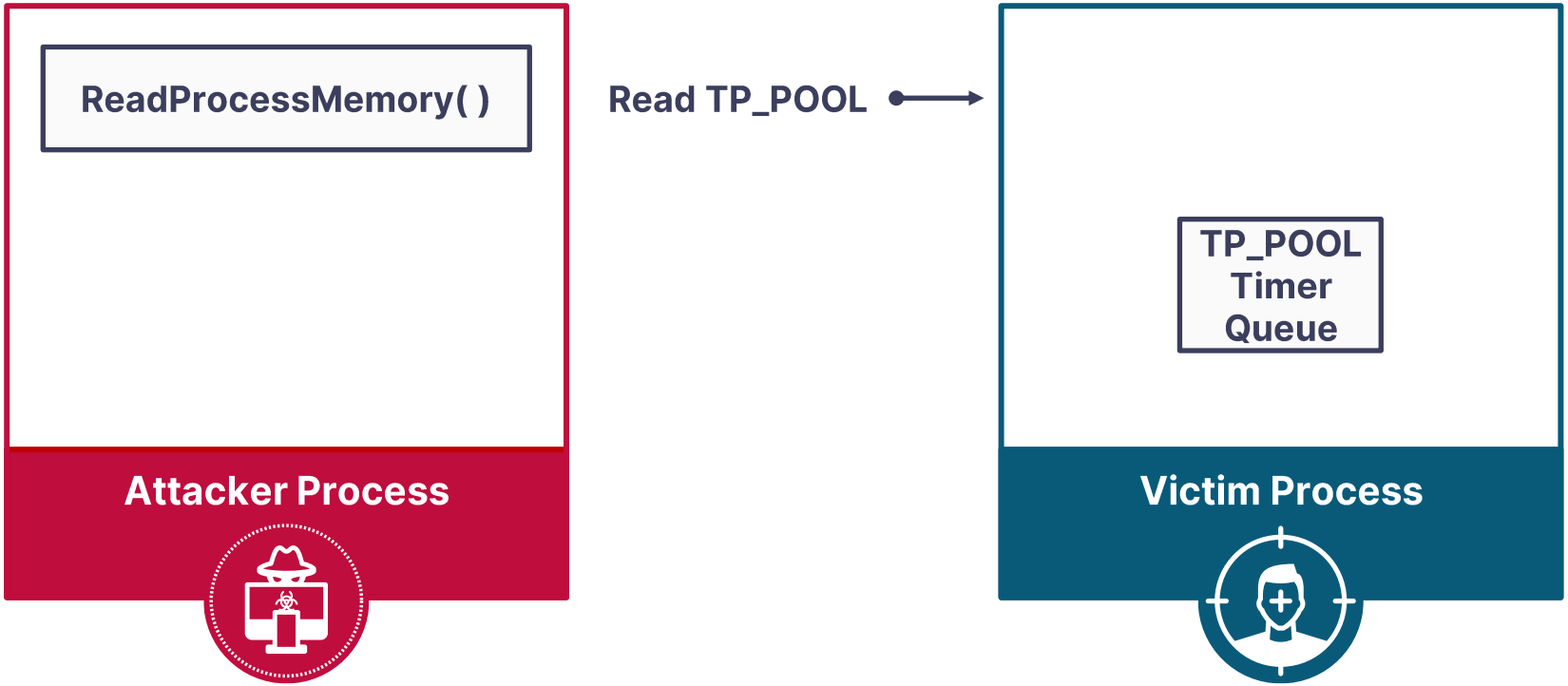
Attacking Thread Pools – TP_TIMER



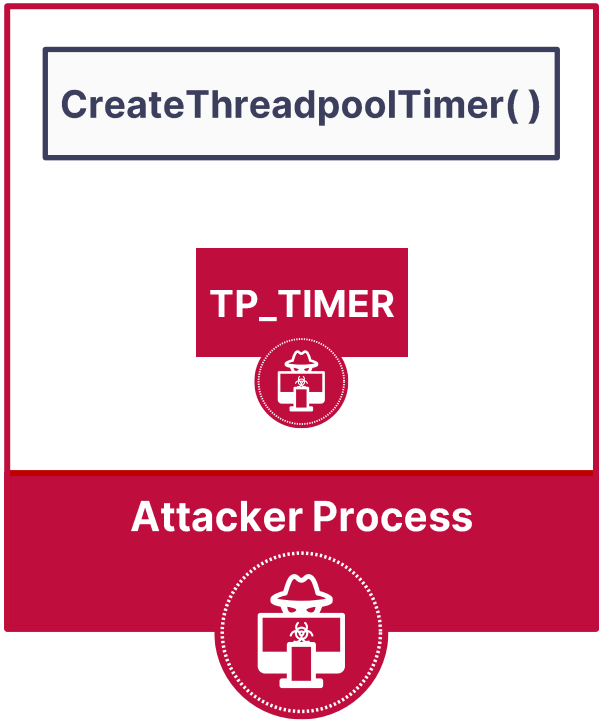
Attacking Thread Pools – TP_TIMER

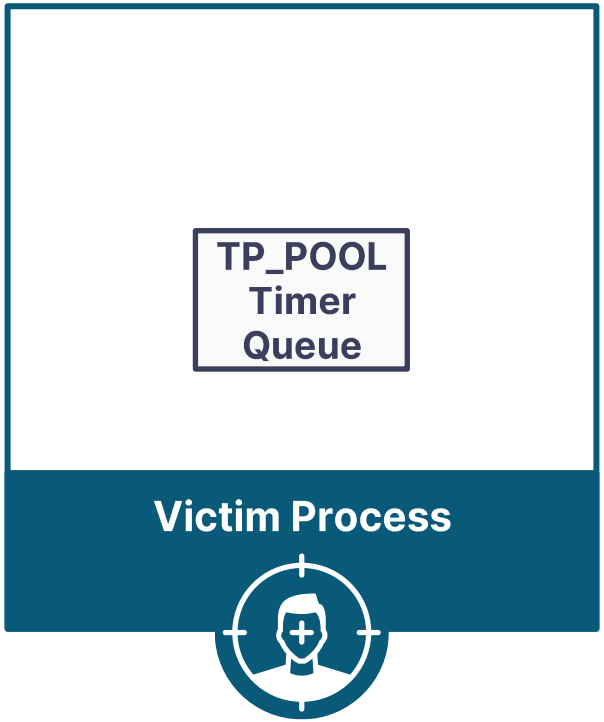


Attacking Thread Pools – TP_TIMER



Attacking Thread Pools – TP_TIMER





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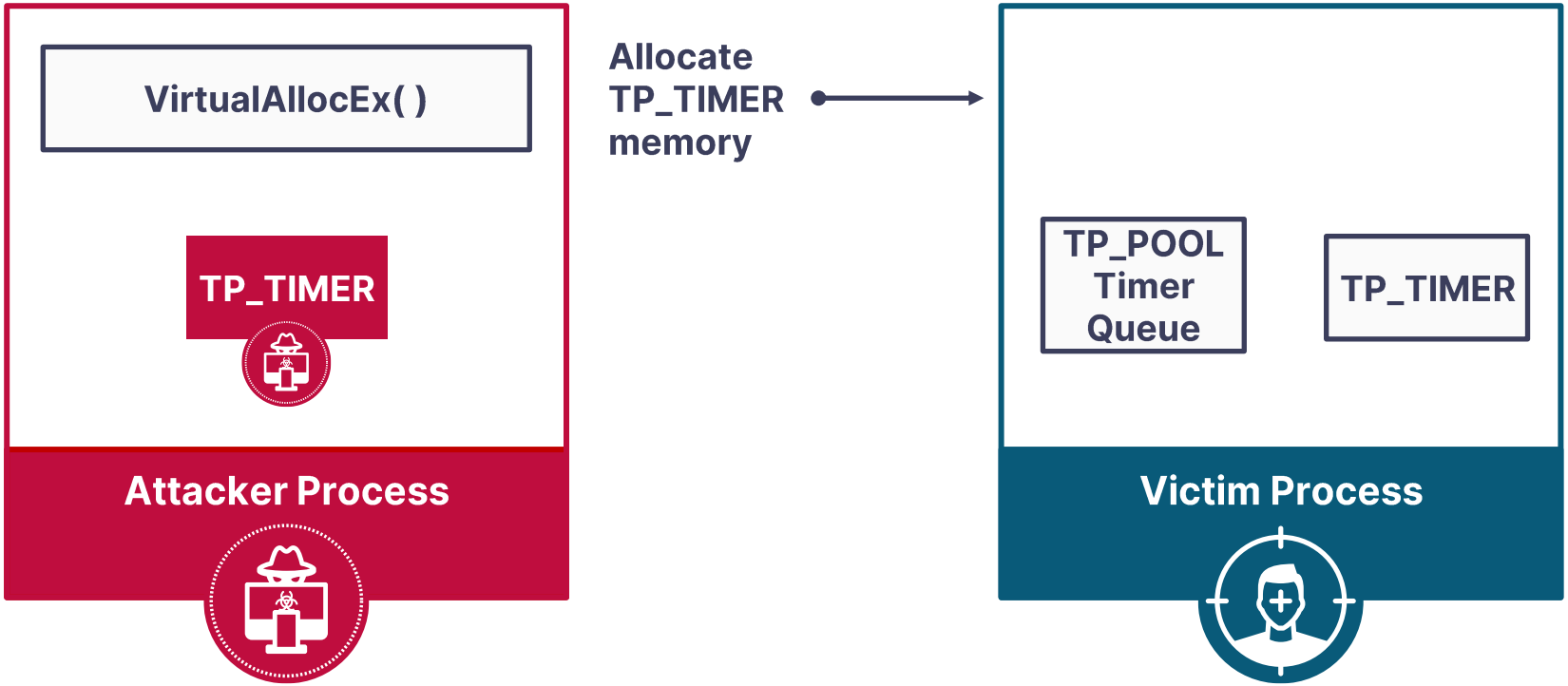

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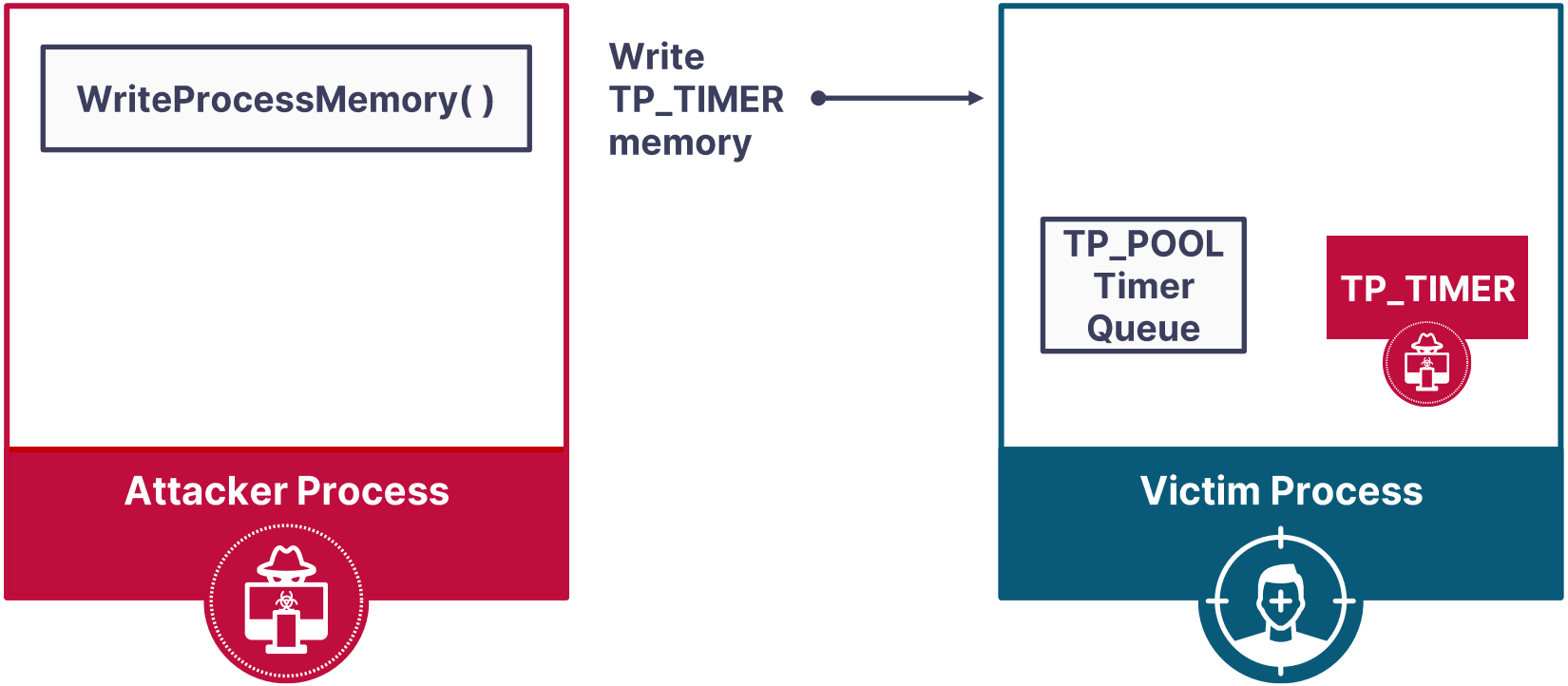
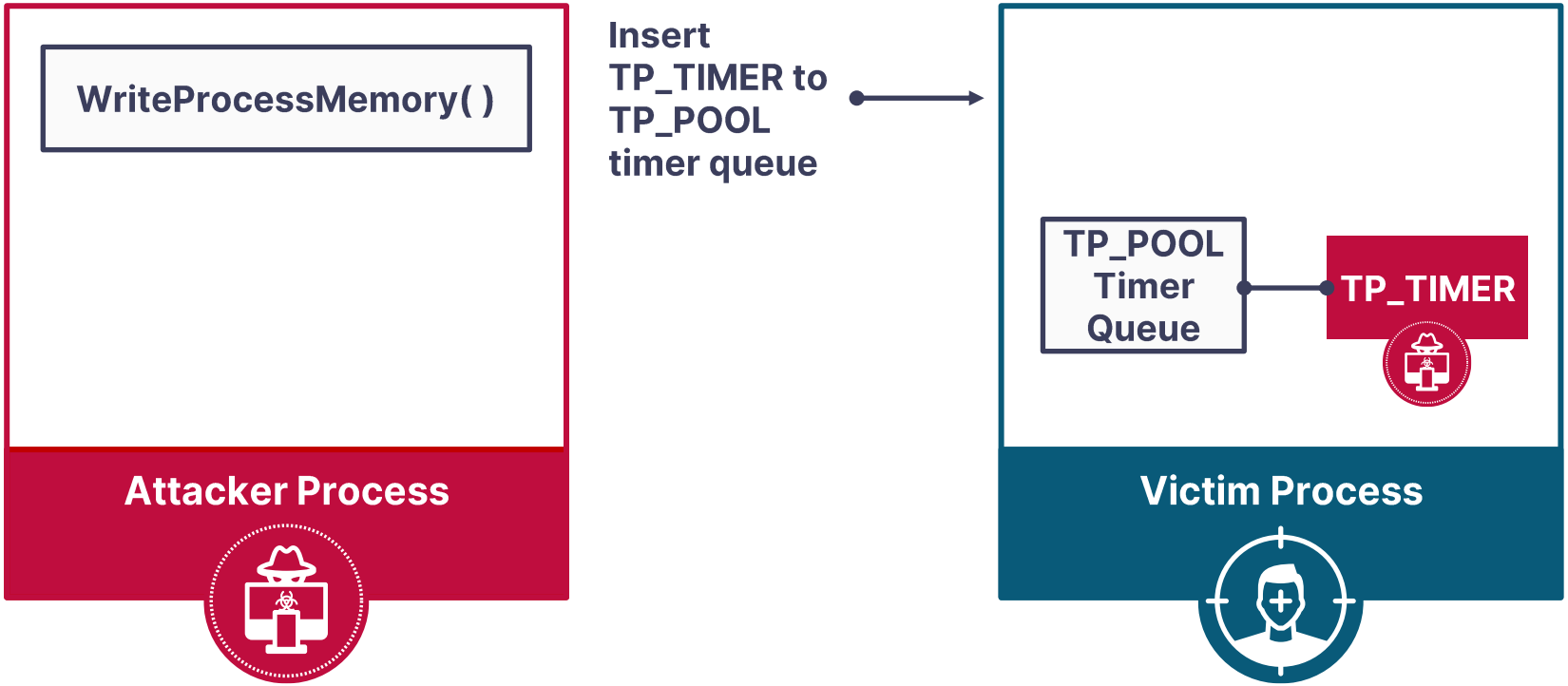
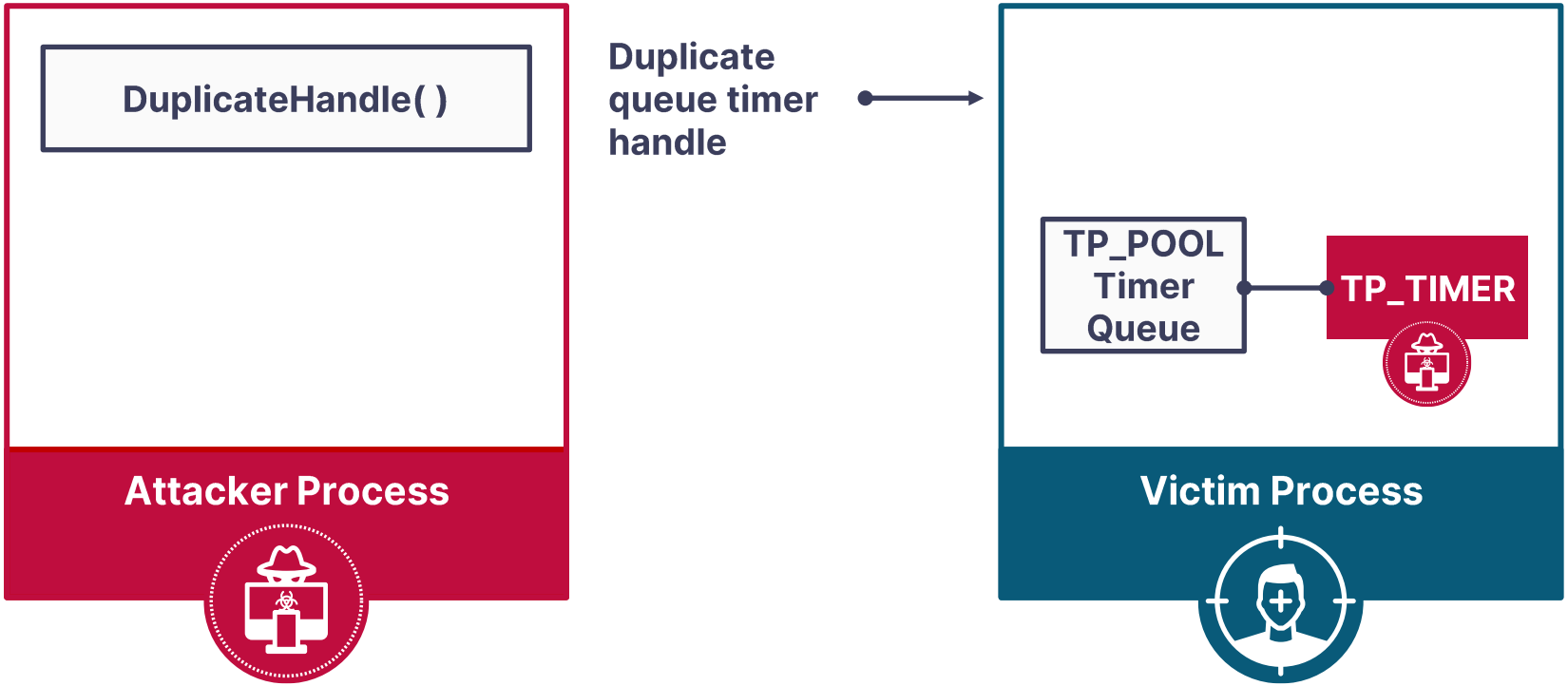


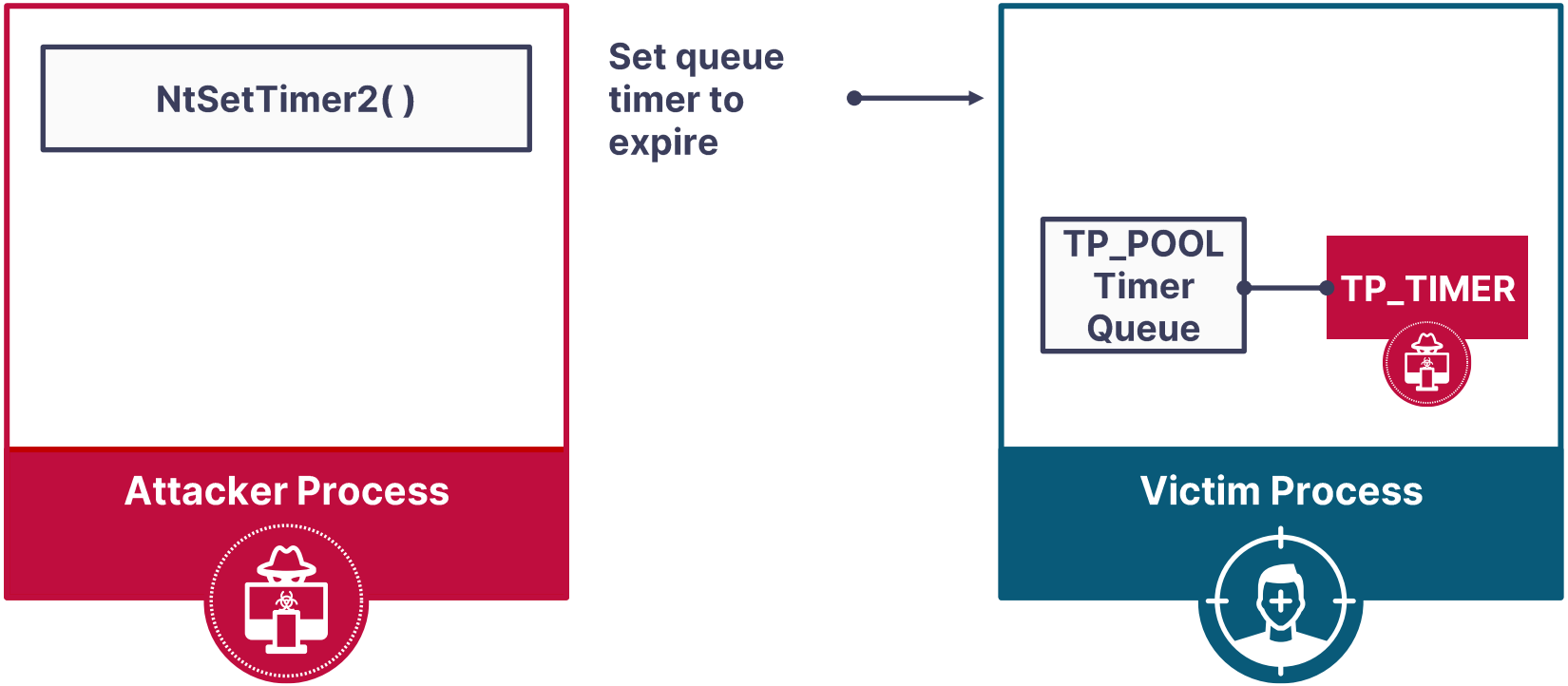
Attacking Thread Pools – TP_TIMER



Attacking Thread Pools – TP_TIMER



Attacking Thread Pools – TP_TIMER



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

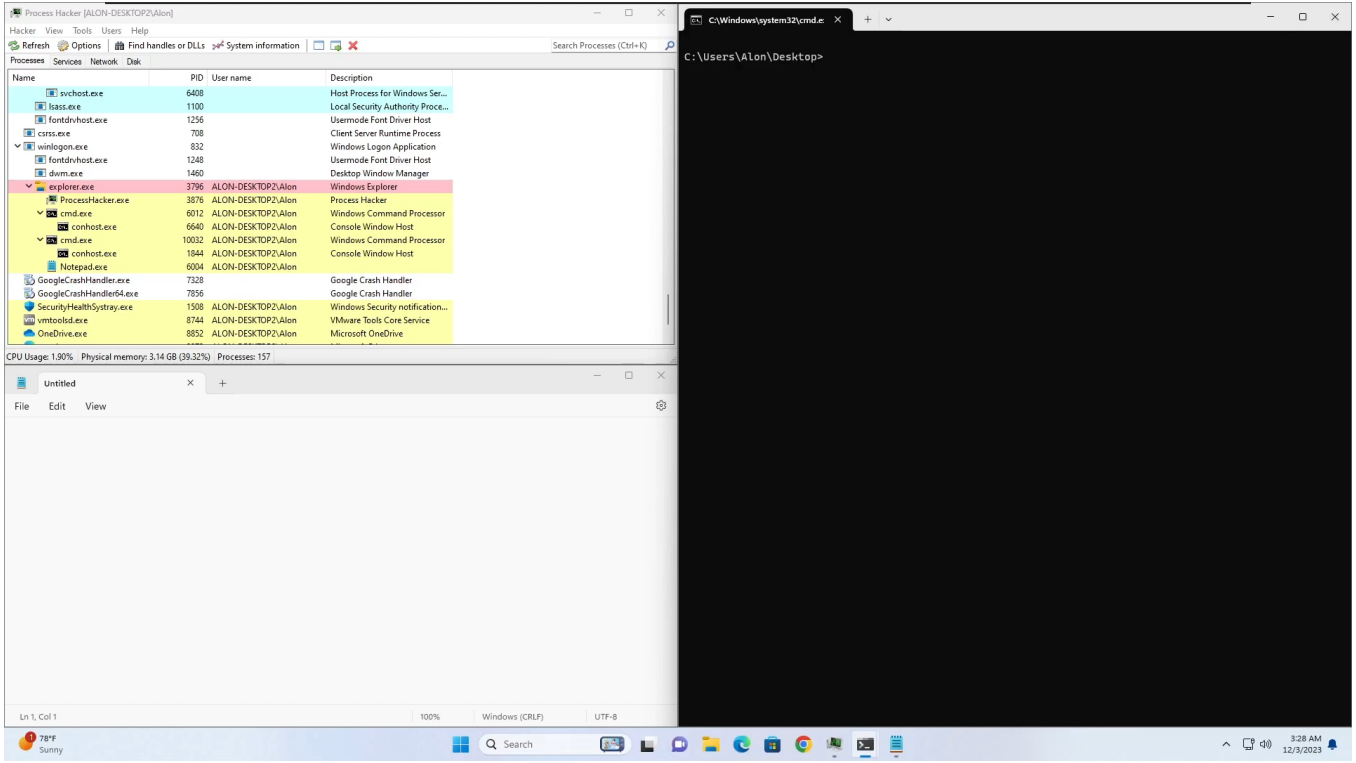
Introducing PoolParty – Affected Products

- 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)

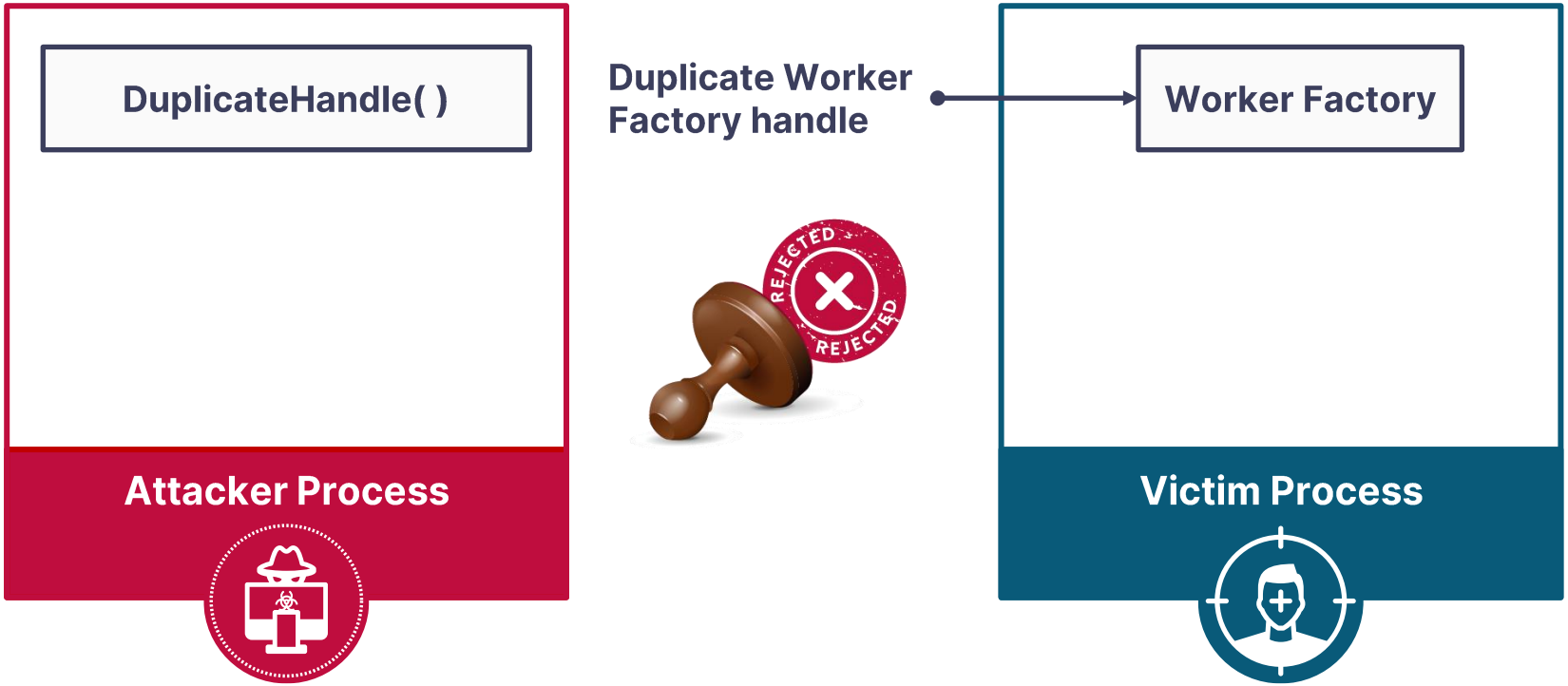
Introducing PoolParty - Demo



How it started

How it’s going

Initial Detection Against PoolParty



Why The Worker Factory Is Needed?

Variant 1 – To query the start routine

Variant 2 – To get the task queue

Variants 3-7 – To get the I/O completion queue handle value

Variant 8 – To get the timer queue

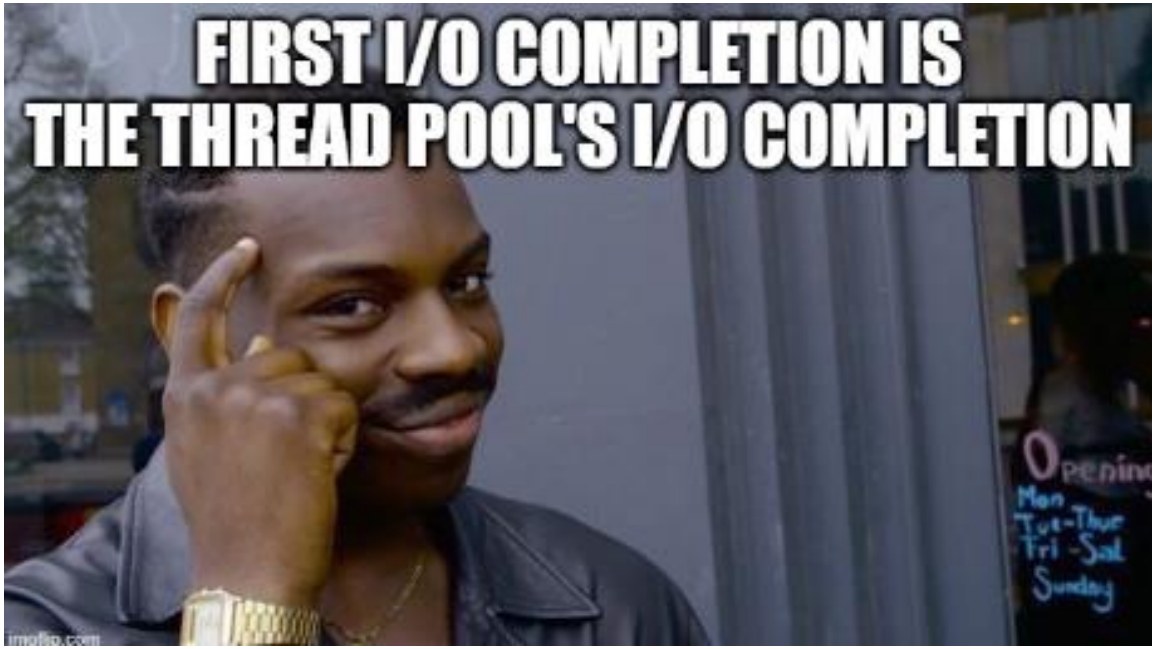
Avoiding Worker Factory Duplication For Variants 3-7

All Windows processes have a thread pool by default

The thread pool is created before the main function is invoked

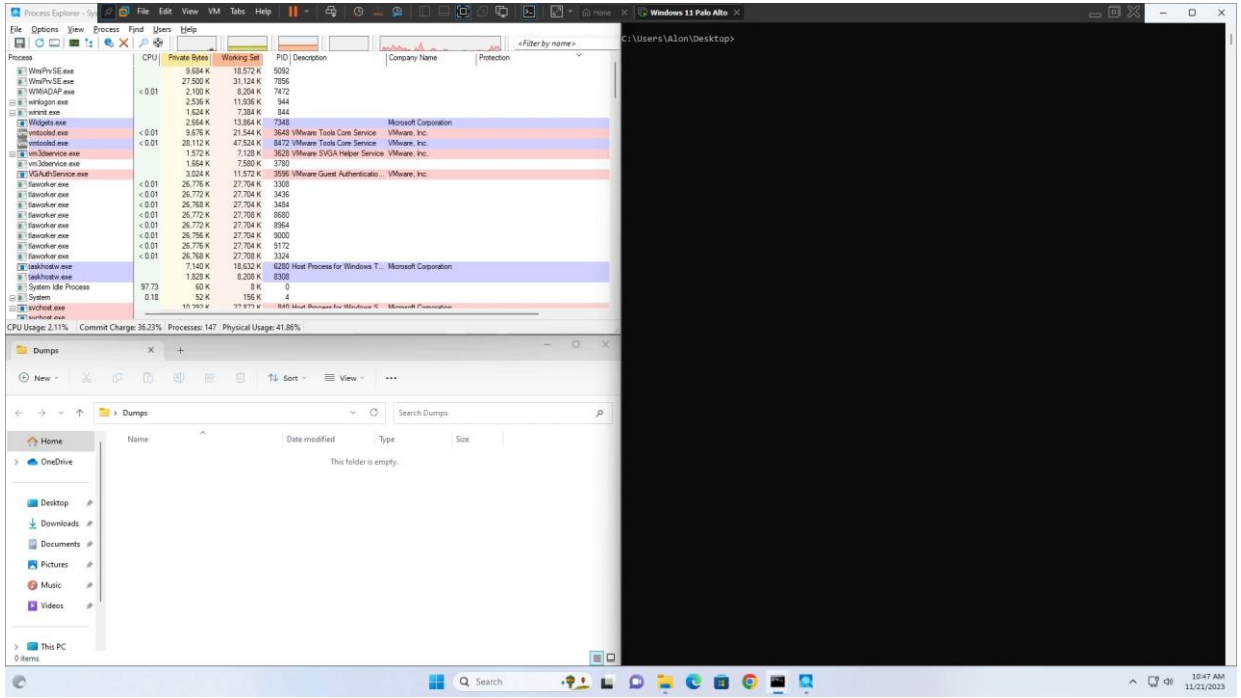
Handle values are sequential

Avoiding Worker Factory Duplication For Variants 3-7

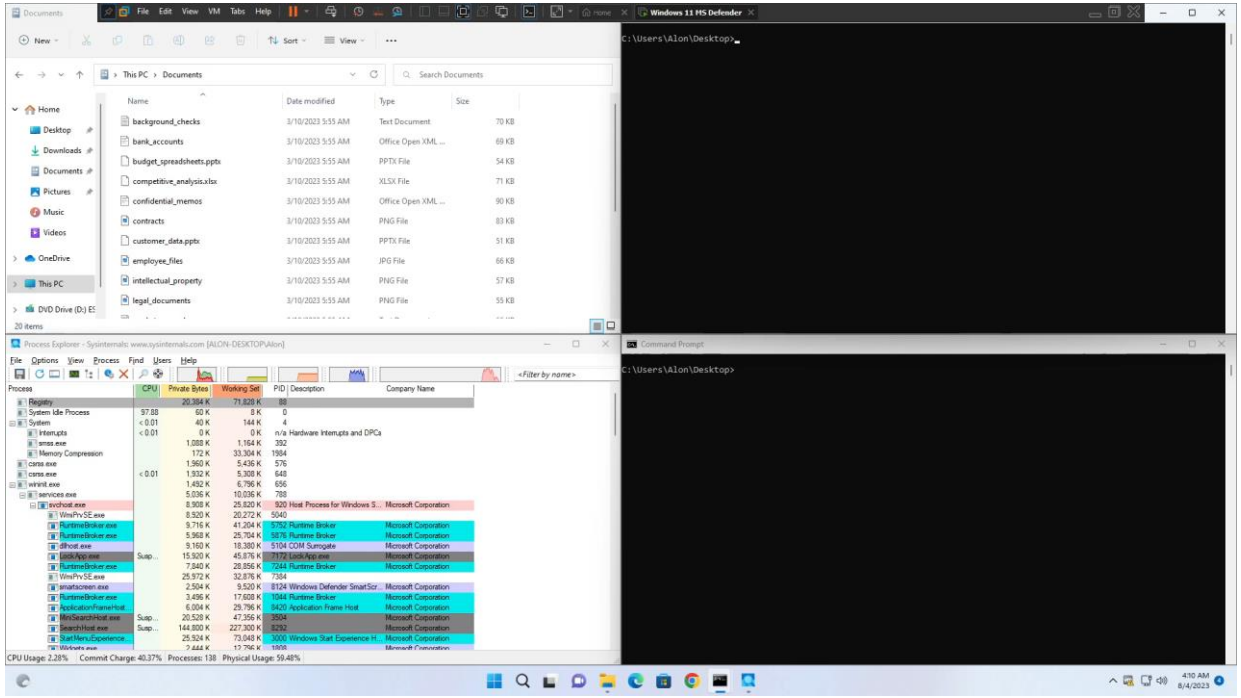


Process Injection Implications

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

PoolParty GitHub + Q&A

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

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