10

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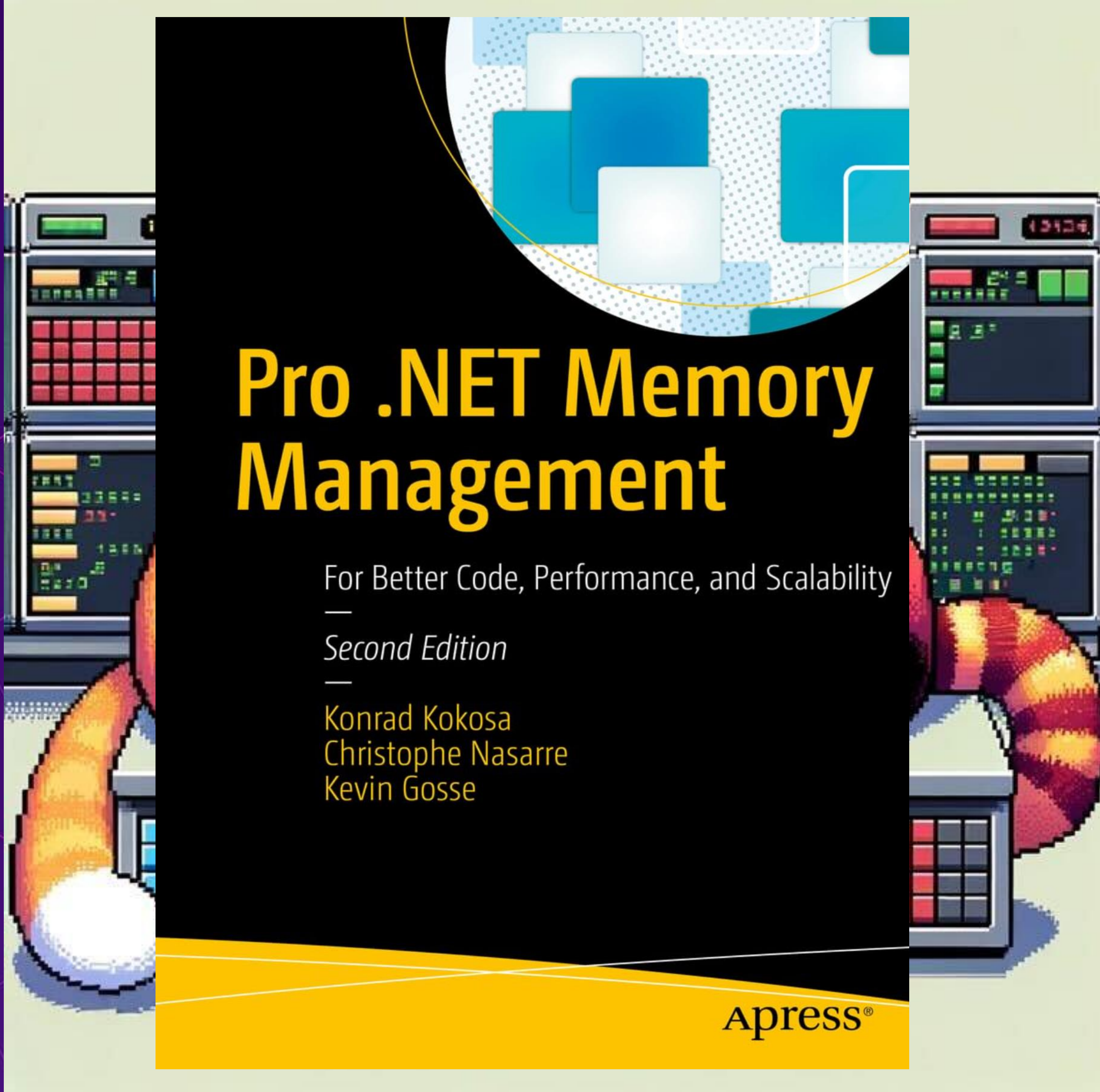
Quoi de neuf pour la gestion de la mémoire en .NET ?

Kevin Gosse
@KooKiz
Christophe Nasarre
@chnasarre

DATADOG



Pro .NET Memory Management

For Better Code, Performance, and Scalability

—

Second Edition

—

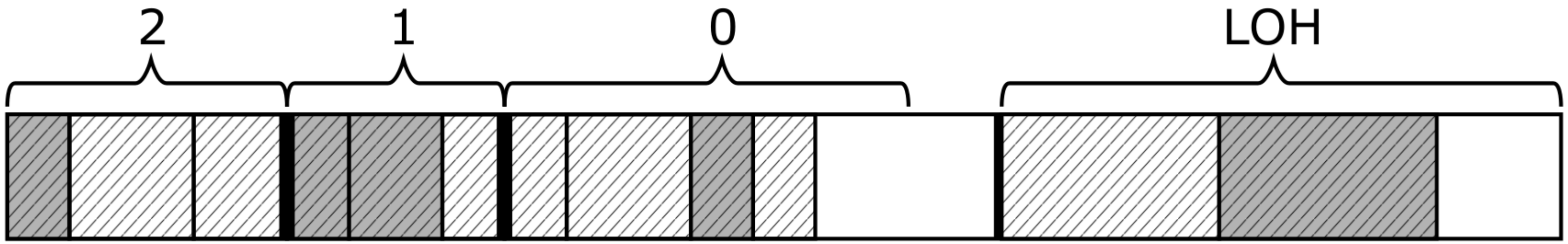
Konrad Kokosa
Christophe Nasarre
Kevin Gosse

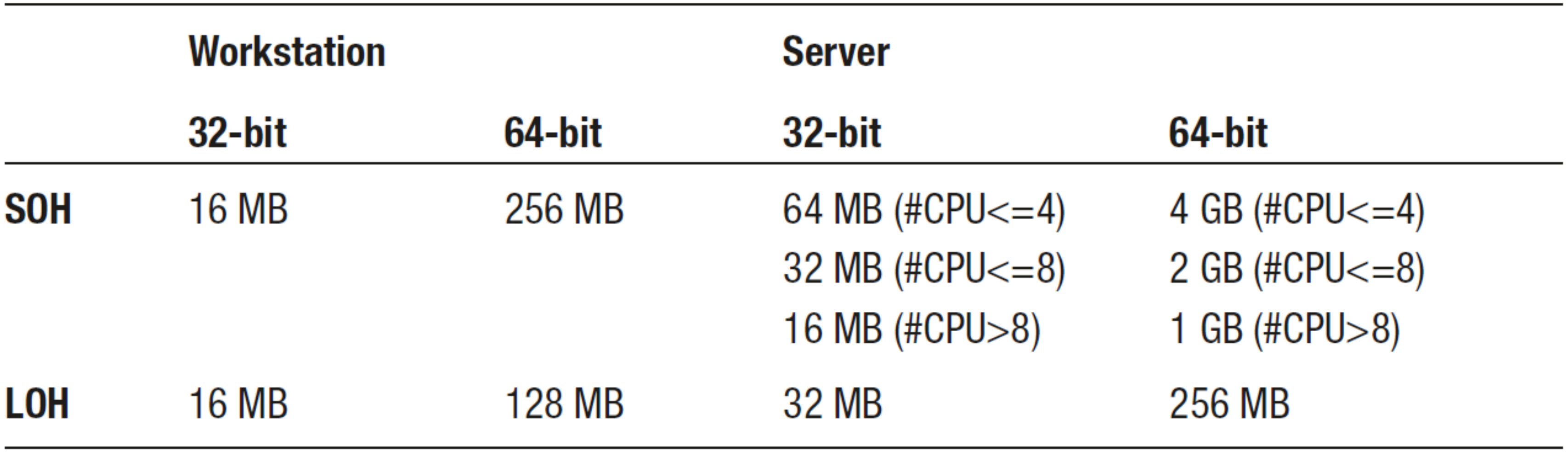
Apress®

Reminder: gen0, gen1, gen2 and LOH

- High level view of the memory layout
  - 3 generations and the LOH

Segments: Ephemeral, gen2 and LOH

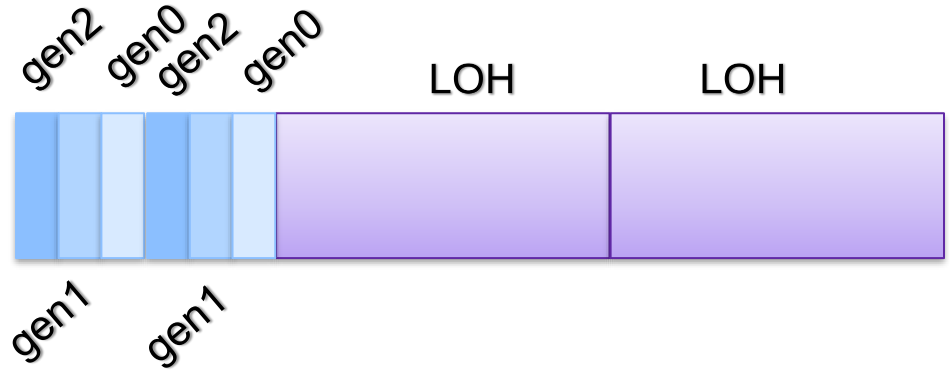




	Workstation		Server	
	32-bit	64-bit	32-bit	64-bit
SOH	16 MB	256 MB	64 MB (#CPU<=4) 32 MB (#CPU<=8) 16 MB (#CPU>8)	4 GB (#CPU<=4) 2 GB (#CPU<=8) 1 GB (#CPU>8)
LOH	16 MB	128 MB	32 MB	256 MB

Regions: LOH and generations

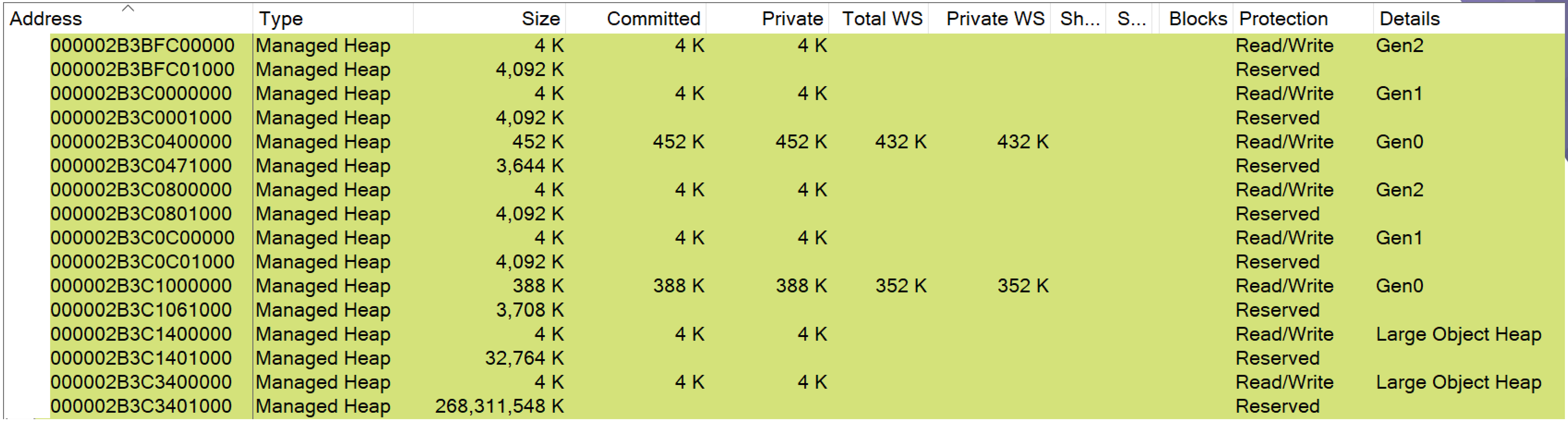
Example: Server mode initialization on a 2 cores machine



SOH : 4 MB
LOH : 8 x 4 MB = 32 MB

How to visualize the heap?

- VMMap for live applications
  - support .NET Core 5+ since v3.4



Address	Type	Size	Committed	Private	Total WS	Private WS	Sh...	S...	Blocks	Protection	Details
000002B3BFC00000	Managed Heap	4 K	4 K	4 K						Read/Write	Gen2
000002B3BFC01000	Managed Heap	4,092 K								Reserved	
000002B3C0000000	Managed Heap	4 K	4 K	4 K						Read/Write	Gen1
000002B3C0001000	Managed Heap	4,092 K								Reserved	
000002B3C0400000	Managed Heap	452 K	452 K	452 K	432 K	432 K				Read/Write	Gen0
000002B3C0471000	Managed Heap	3,644 K								Reserved	
000002B3C0800000	Managed Heap	4 K	4 K	4 K						Read/Write	Gen2
000002B3C0801000	Managed Heap	4,092 K								Reserved	
000002B3C0C00000	Managed Heap	4 K	4 K	4 K						Read/Write	Gen1
000002B3C0C01000	Managed Heap	4,092 K								Reserved	
000002B3C1000000	Managed Heap	388 K	388 K	388 K	352 K	352 K				Read/Write	Gen0
000002B3C1061000	Managed Heap	3,708 K								Reserved	
000002B3C1400000	Managed Heap	4 K	4 K	4 K						Read/Write	Large Object Heap
000002B3C1401000	Managed Heap	32,764 K								Reserved	
000002B3C3400000	Managed Heap	4 K	4 K	4 K						Read/Write	Large Object Heap
000002B3C3401000	Managed Heap	268,311,548 K								Reserved	

DPAD

DPAD

- Dynamic Promotion and Demotion
- `DOTNET_GCEnableSpecialRegions=1`

Experimental feature!

- Rule 1: Sweep in plan (SIP)
  - What is sweep?
  - What is plan?

DPAD

Mark

Plan

Compact

Sweep

Relocate

DPAD

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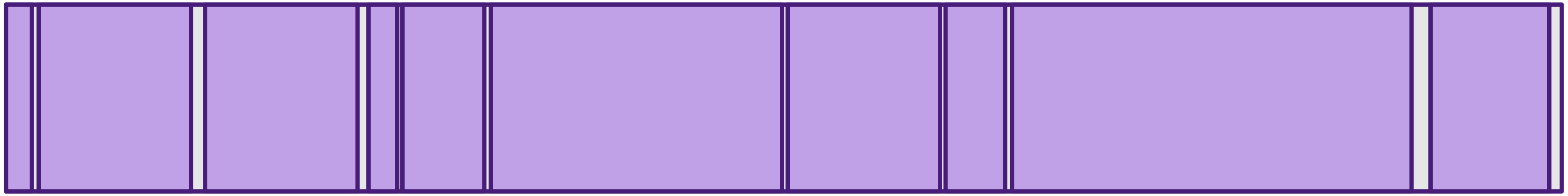

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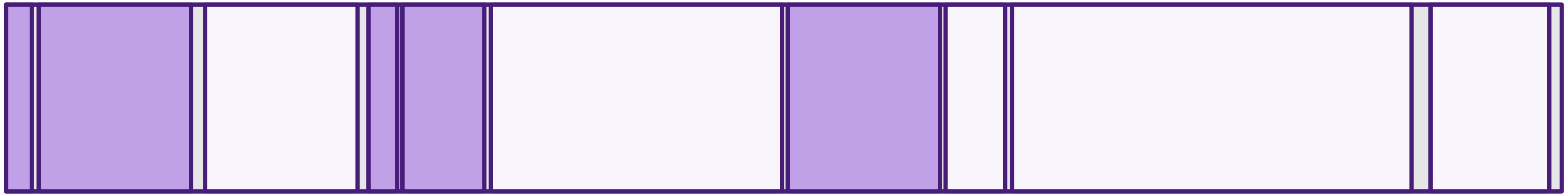

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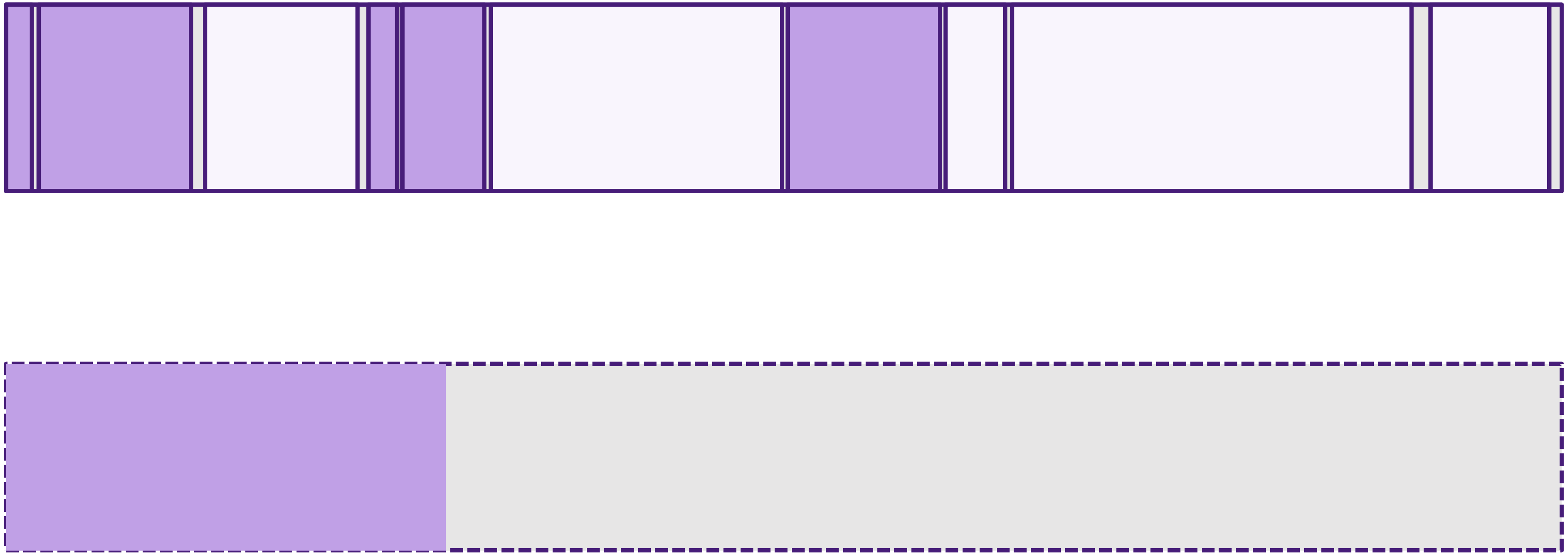

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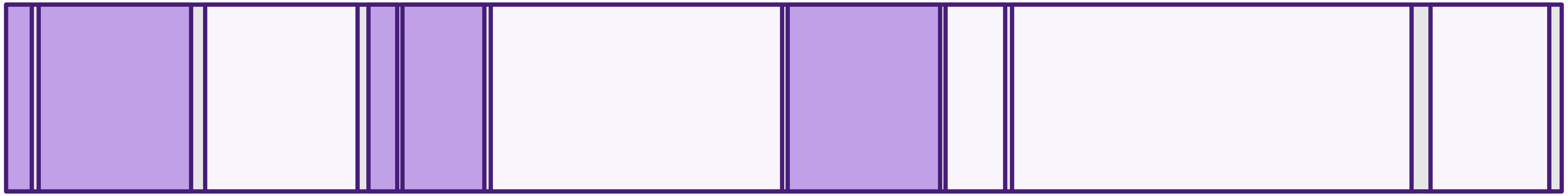

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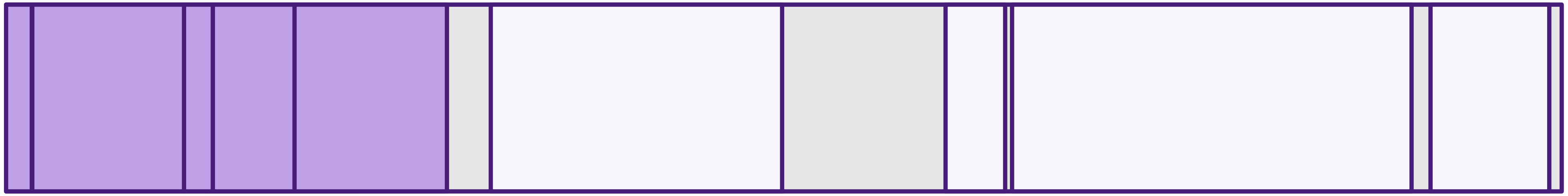

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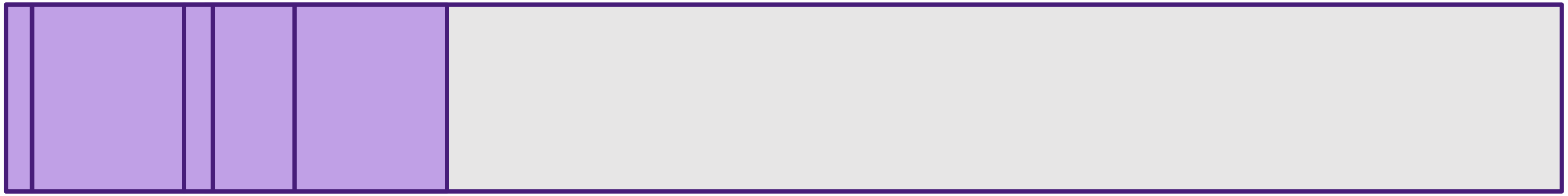

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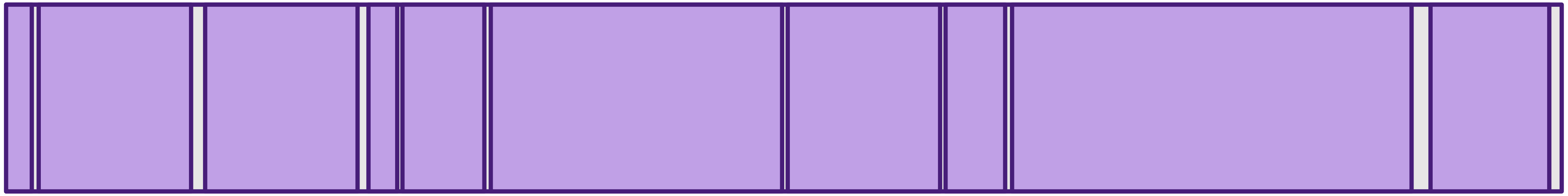

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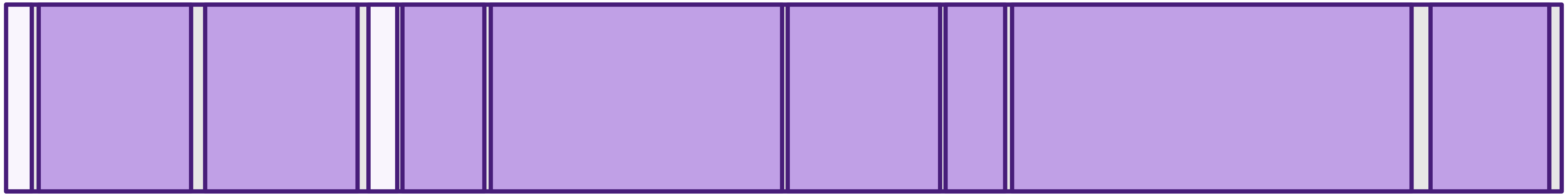

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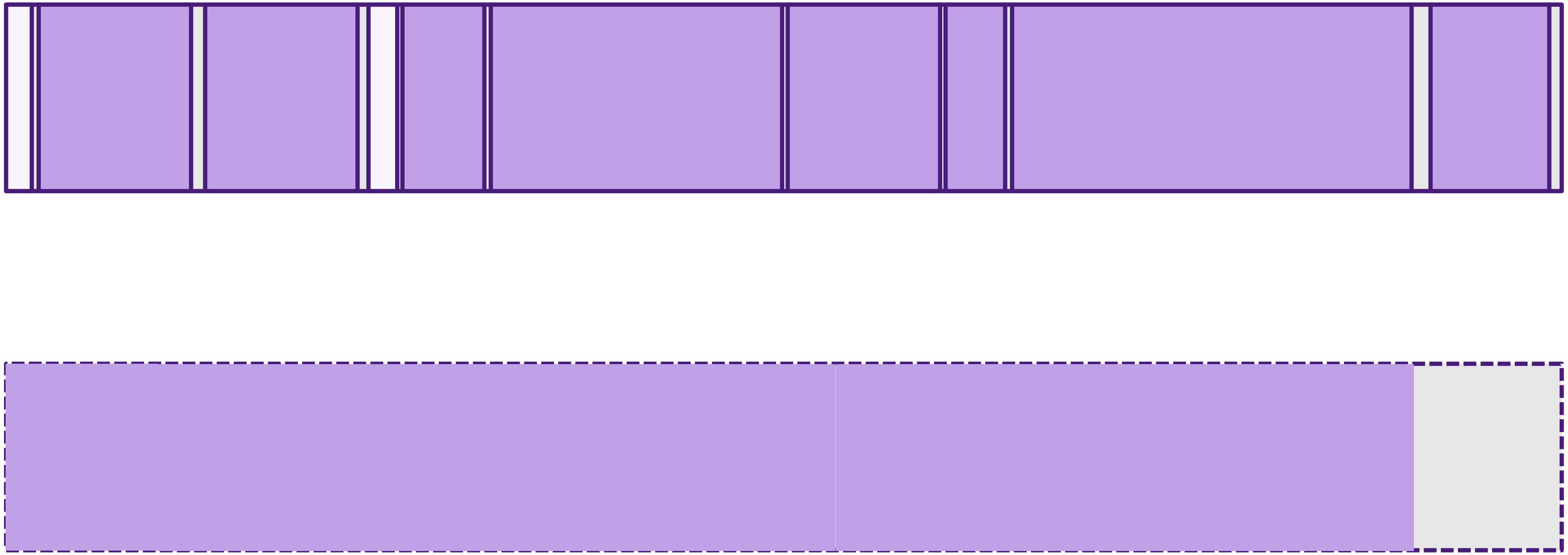
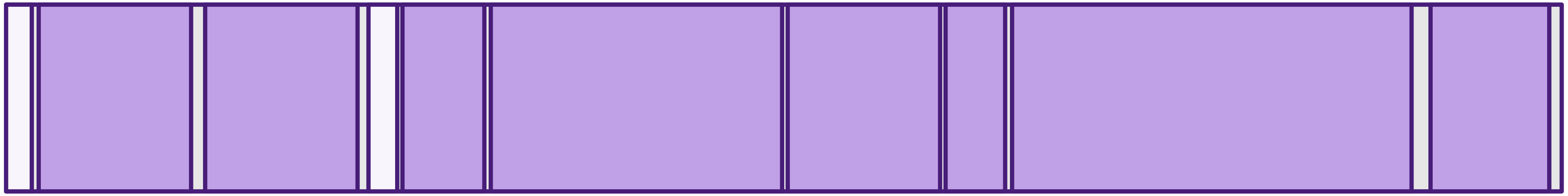


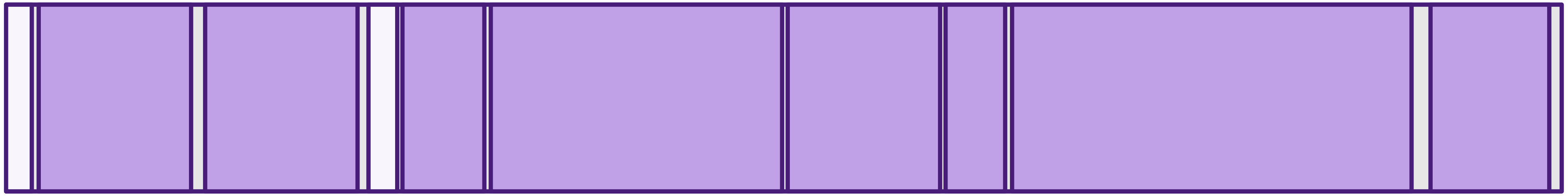
Mark Plan Compact Relocate

Sweep



DPAD

- Rule 1: Sweep in plan (SIP) : during plan phase, if survival rate > 90%



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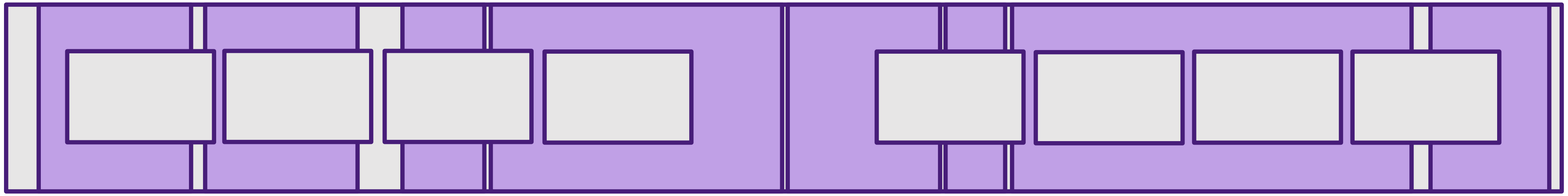
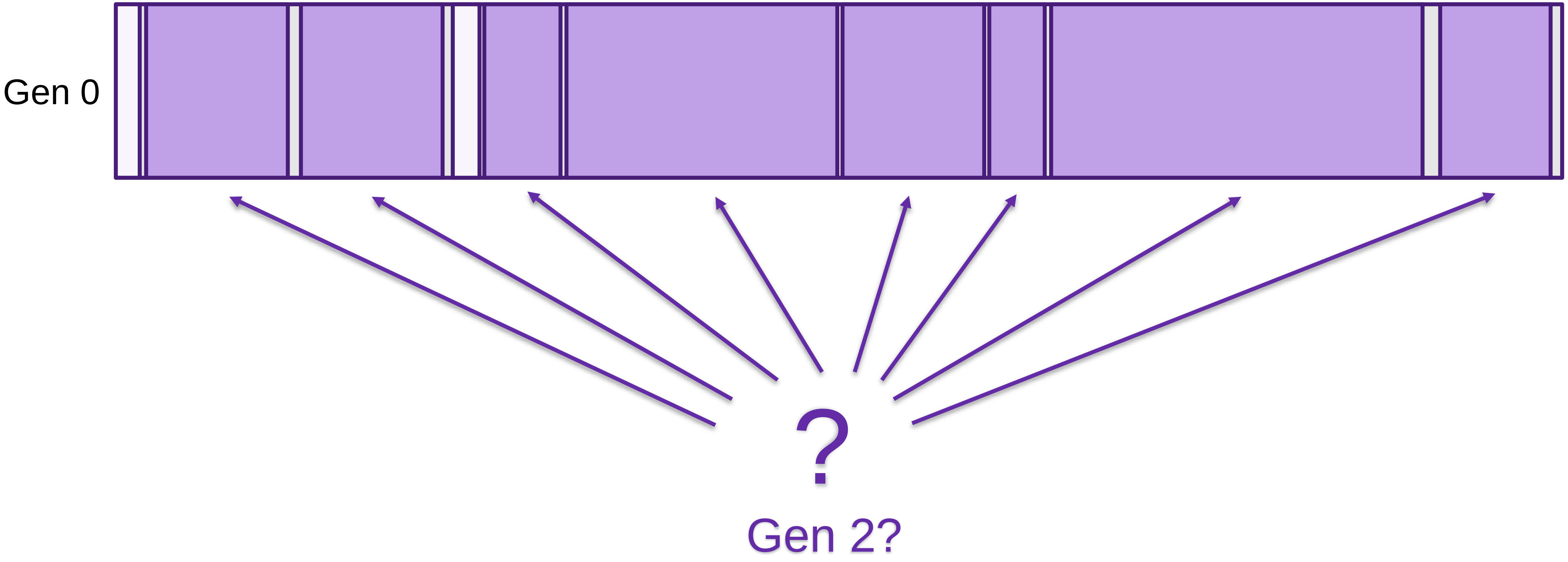
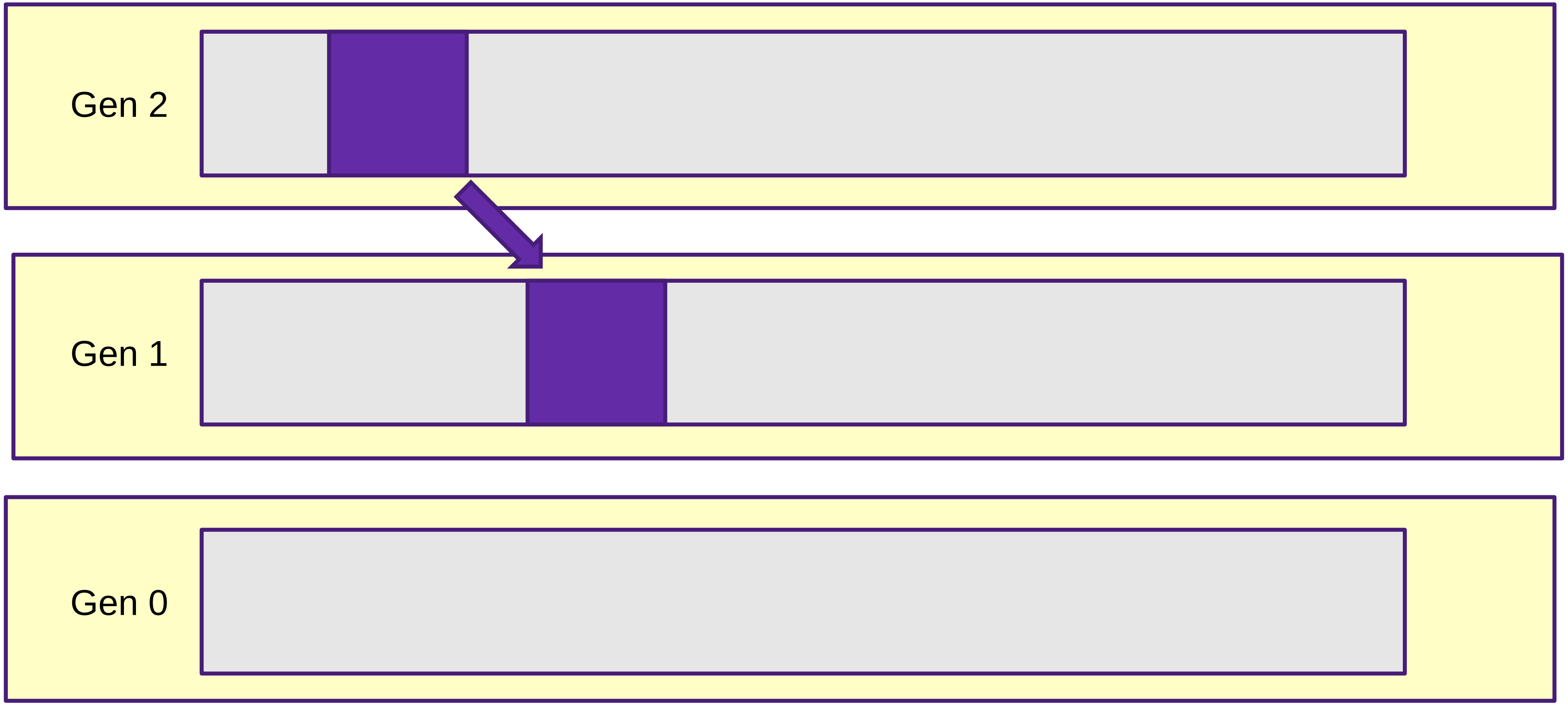


- Rule 2: Dynamic promotion



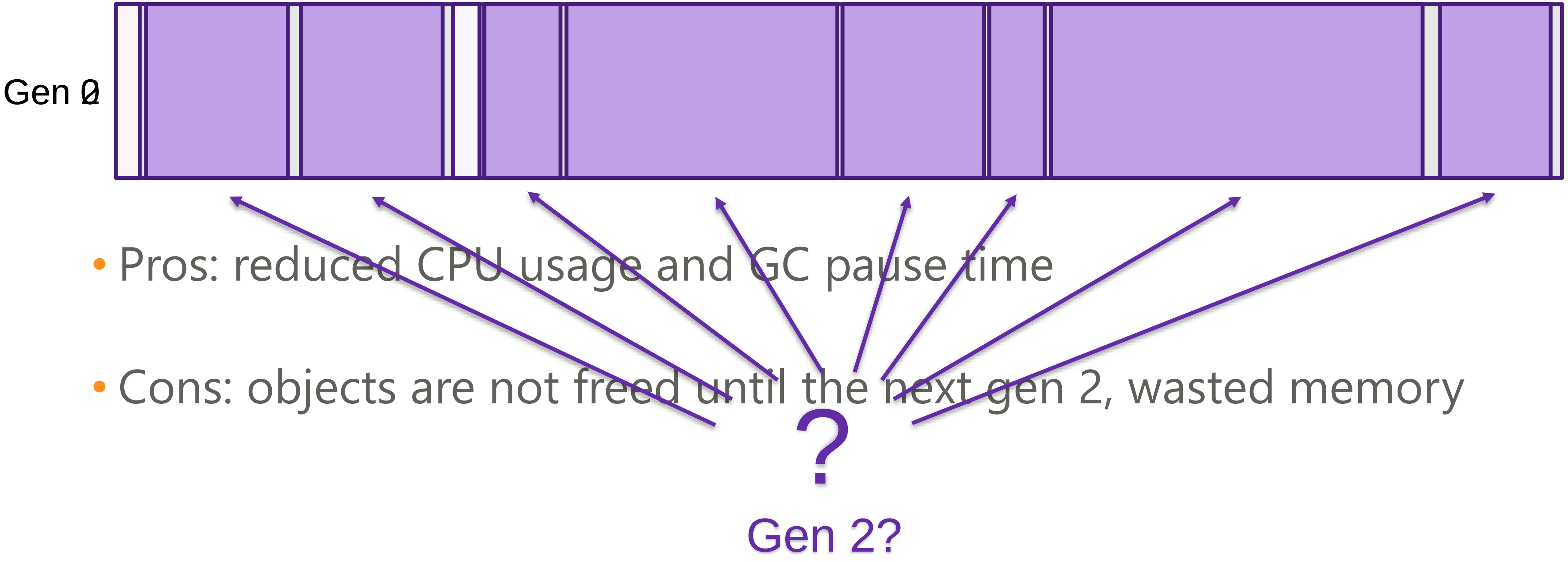
DPAD

- Rule 2: Dynamic promotion



DPAD

- Rule 2: Dynamic promotion : if gen 2 roots > 90%



- Pros: reduced CPU usage and GC pause time
- Cons: objects are not freed until the next gen 2, wasted memory

DPAD

- `DOTNET_GCEnableSpecialRegions=1`
- Takes advantage of regions to reduce the amount of work done by the GC
- Increases the working set
- Broken on .NET 7/8

In gen0 or LOH? That is the question…

In gen0 or LOH? That is the question…

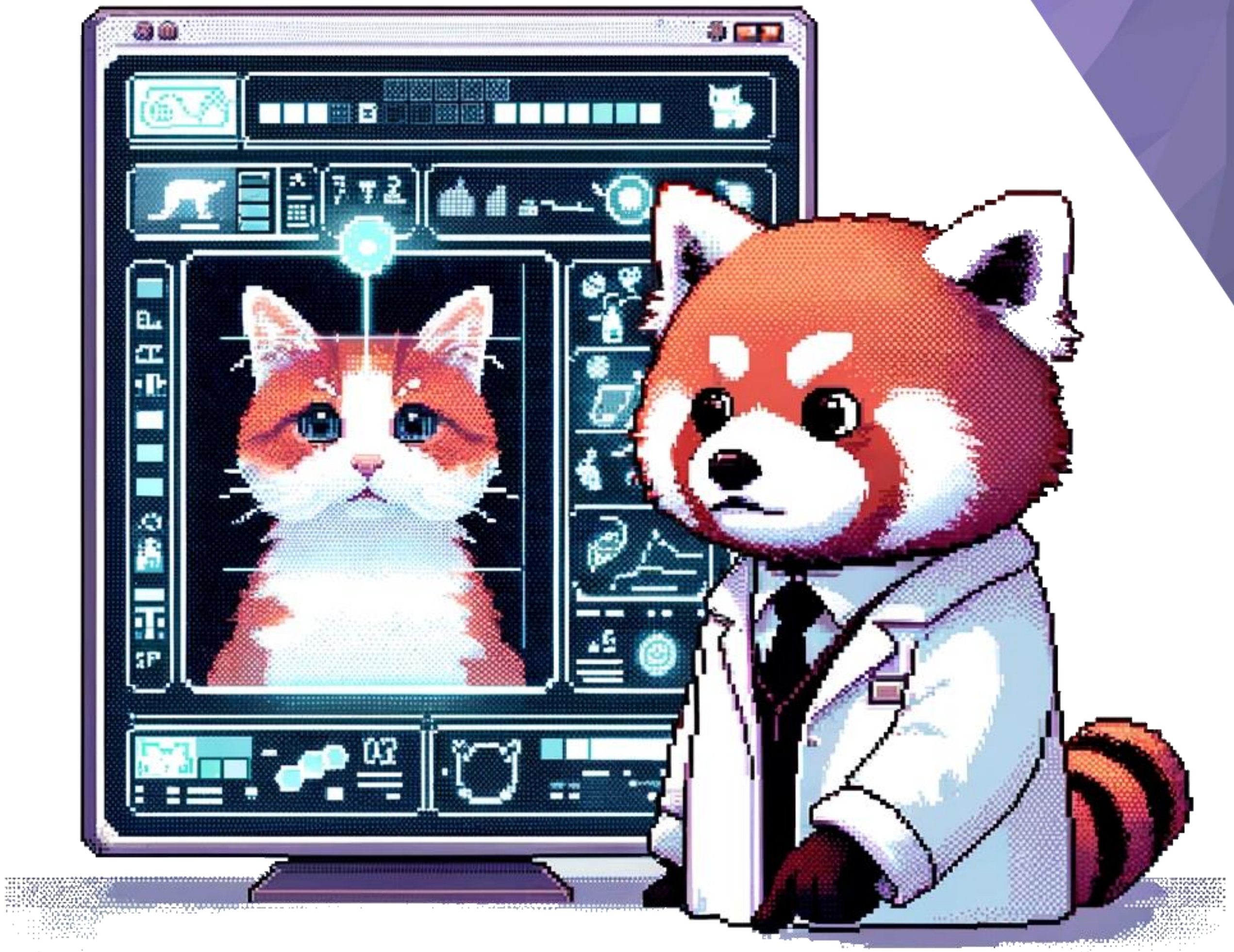
- Large Object Heap
  - possible to optimize large allocations scenario

- Example of threshold impact

```
řsîŵǻţê șţǻţîç ŵộîđ Aľľộçǻţê îŋţ çộụŋţ
    čỳţê   čụǧǧês   ŋụľľ
    ǧộs  îŋţ î   。  î   çộụŋţ   î
        čụǧǧês   ŋêx čỳţê ¨_。。。
        čụǧǧês  。    čỳţê î
```

Threshold	Duration	gen2	gen1	gen0
85000	1020 ms	2702	2702	2702
102400	424 ms	0	1	1010

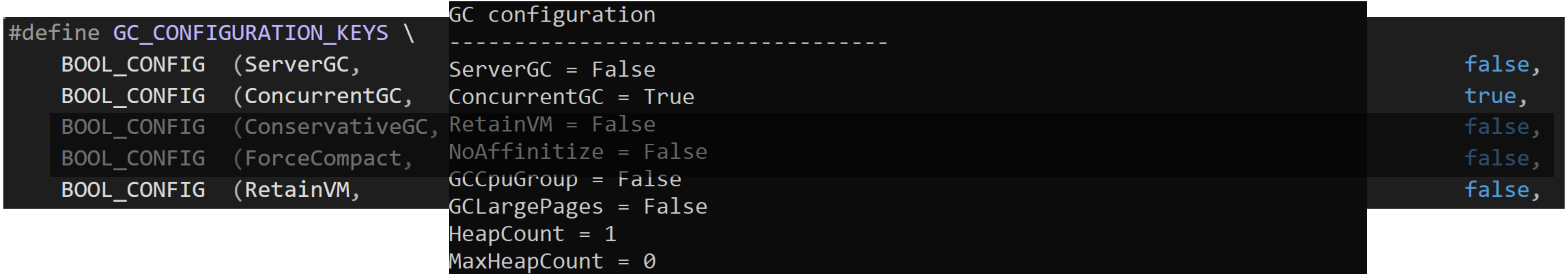
How to get GC configuration?



How to get GC configuration?

- What is the GC configuration?
  - `GC.GetConfigurationVariables()`
  - …but not `DOTNET_GCLOHThreshold`

src/coreclr/gc/gcconfig.h



```
#define GC_CONFIGURATION_KEYS \
    BOOL_CONFIG  (ServerGC,                                                          false,
    BOOL_CONFIG  (ConcurrentGC,                                                      true,
    BOOL_CONFIG  (ConservativeGC,                                                    false,
    BOOL_CONFIG  (ForceCompact,                                                      false,
    BOOL_CONFIG  (RetainVM,                                                          false,
```

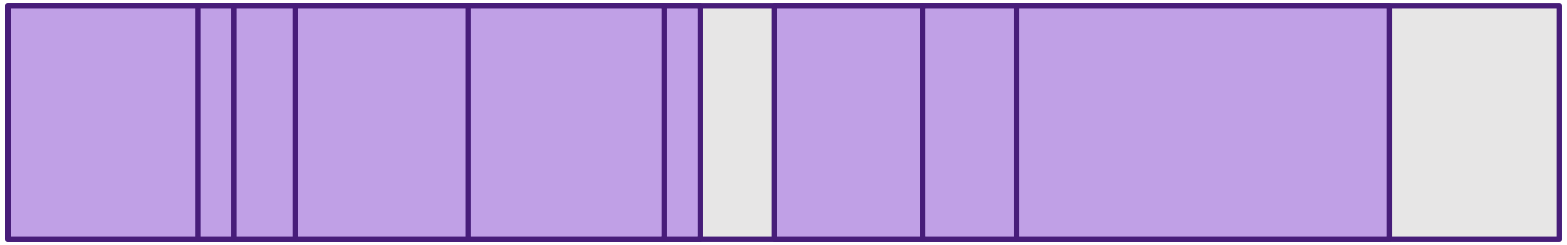
```
GC configuration
----------------------------------
ServerGC = False
ConcurrentGC = True
RetainVM = False
NoAffinitize = False
GCCpuGroup = False
GCLargePages = False
HeapCount = 1
MaxHeapCount = 0
```

DATAS

Why does my heap get so big?

Background GC

Why does my heap get so big?



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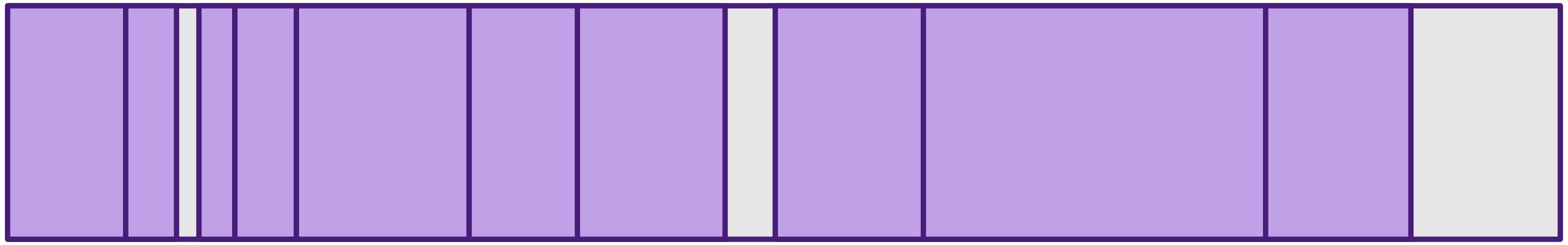

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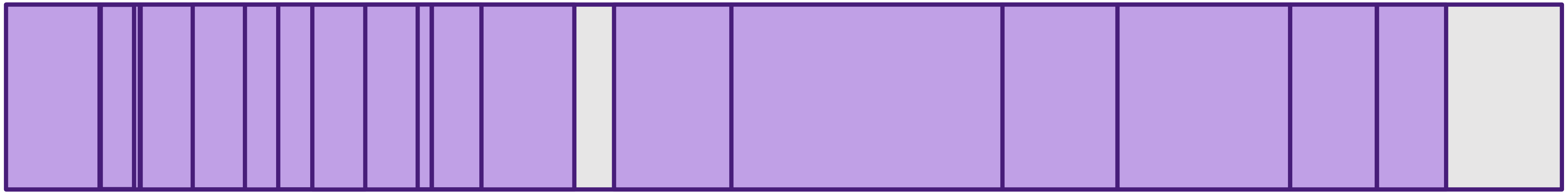


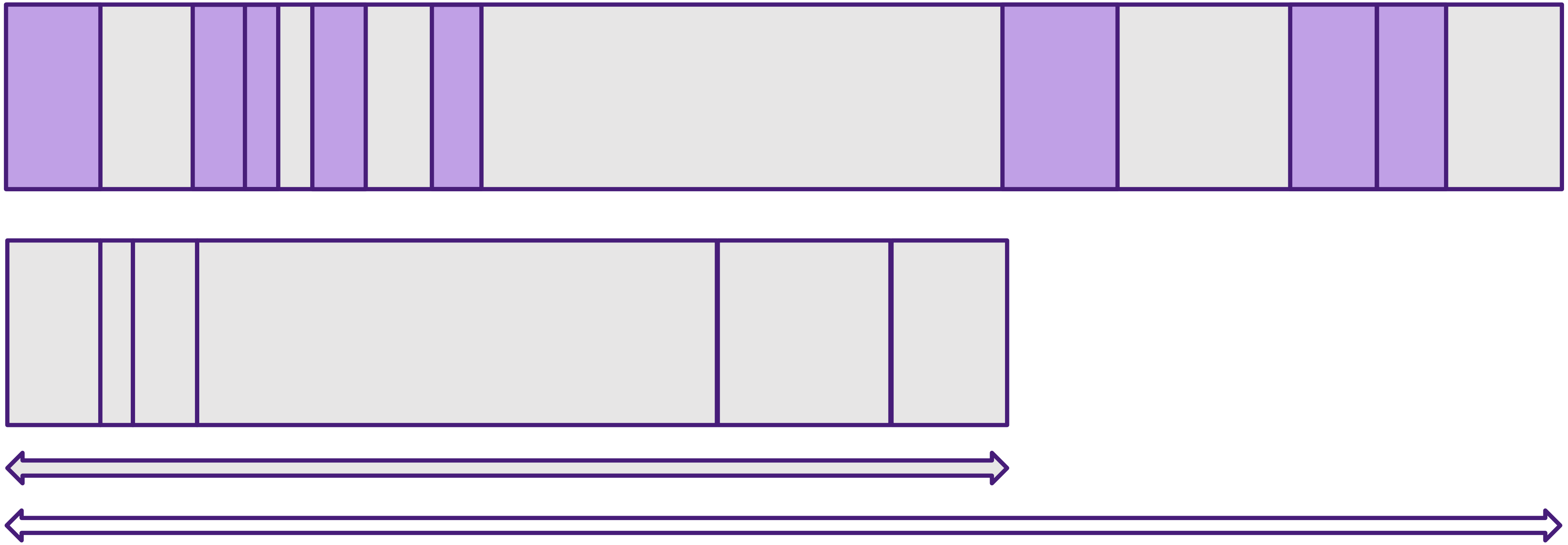
Background GC

GCConserveMemory

- `DOTNET_gcConserveMemory=[1-9]`
- Available on .NET Framework 4.8 and .NET 6+
- Defines the maximum amount of “fragmentation” (free objects) in gen 2 and LOH
- 1=10% of live data (90% of fragmentation)
  9=90% of live data (10% of fragmentation)

GCConserveMemory

```
DOTNET_gcConserveMemory=4  => 60% of fragmentation
```



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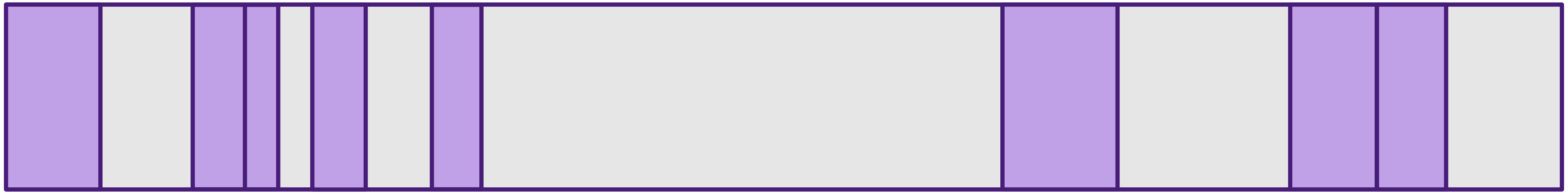

Compacting GC

GCConserveMemory

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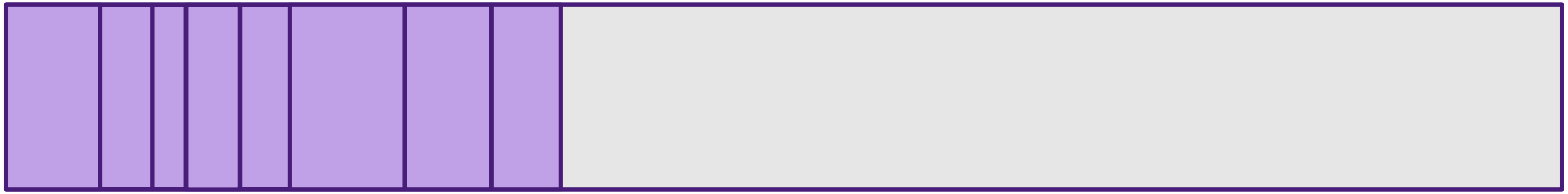

Compacting GC

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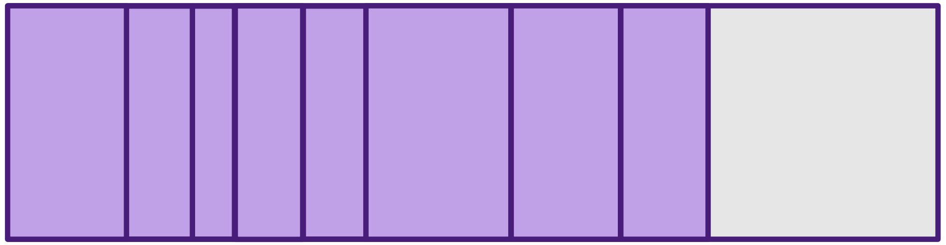


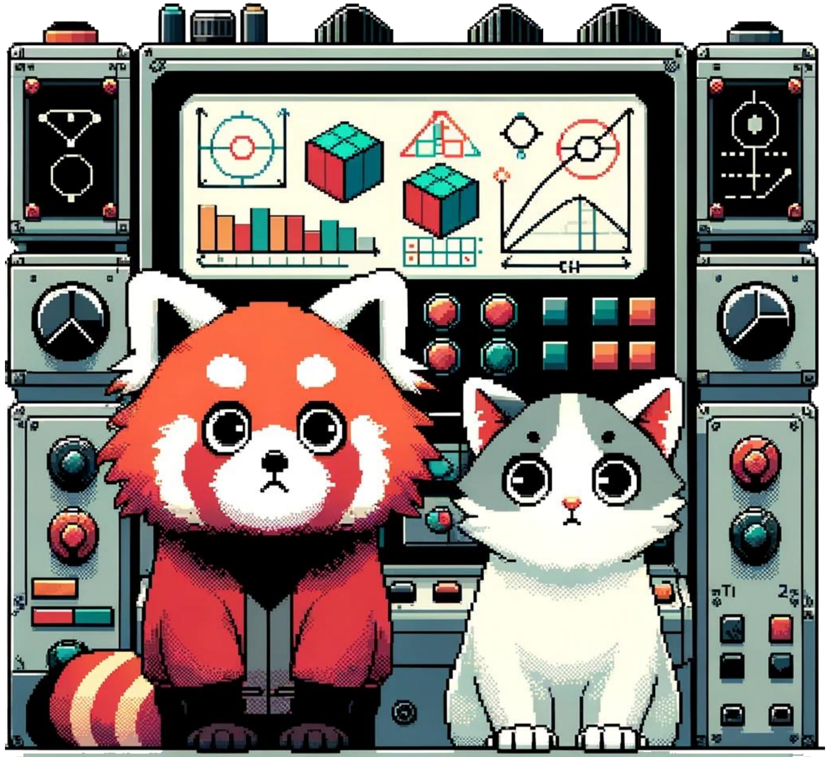
Compacting GC

Can we do better?

- Reduce gen 0 budget: `DOTNET_GCGen0MaxBudget`

- Reduce the number of heaps: `DOTNET_GCHeapCount`

- There has to be a better way…



Can we do better?

- Dynamically Adapting To Application Sizes (DATAS) : `DOTNET_GCDynamicAdaptationMode=1`
- Enabled by default in .NET 9
- Implies `DOTNET_GCConserveMemory=5` but can be tuned separately
- Automatically disabled if `DOTNET_GCHeapCount` is set

Can we do better?

- Gen 0 budget is adjusted depending on the size of other generations
- The number of heaps is adjusted depending on the workload
- Heuristics based on, over the last 3 GCs:

  Time spent in GC
  Time spent in allocation lock
  Time spent in the last gen 2 collection
  Minimum heap size
  Total heap size

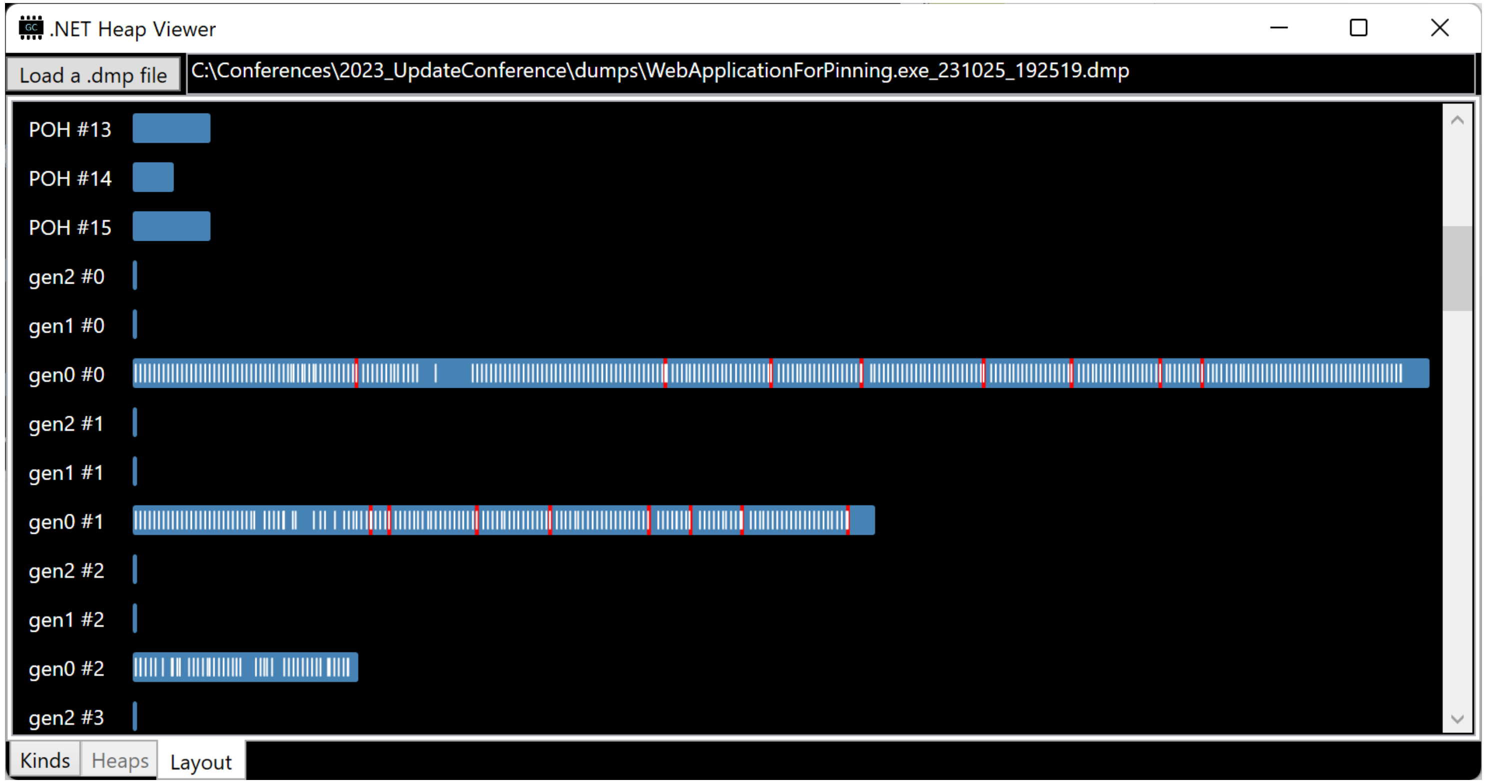
Welcome to the POH!

Welcome to the POH!

- The problem with pinned objects
  - increased memory usage (and more)

- Pinned Object Heap
  - `GC.AllocateArray` to pre-allocate pinned arrays as buffer for P/Invoke calls

- Use ClrMD to look into it
  - GCHandle for existing pinned objects (especially for asynchronous code)
  - all objects in the new POH


.NET Heap Viewer

Load a .dmp file C:\Conferences\2023_UpdateConference\dumps\WebApplicationForPinning.exe_231025_192519.dmp

String Literals… and the NonGC Heap

- String literals are eternal
  - no need to be managed by the GC
  - also for System.Type and simple readonly static fields (object, arrays of basic types)

- Allocation size heuristic

```
if < 64 KB then in NGCH
if < 85000 bytes then in gen0
else in LOH
```

Usages of the NonGC Heap

- Better JITted code
  - less pointer indirections
  - but more - https://github.com/dotnet/runtime/issues/76151

- Use ClrMD to look into it
  - but only for instanciated ones
  - System.Reflection.PortableExecutable.PEReader for the compiled ones

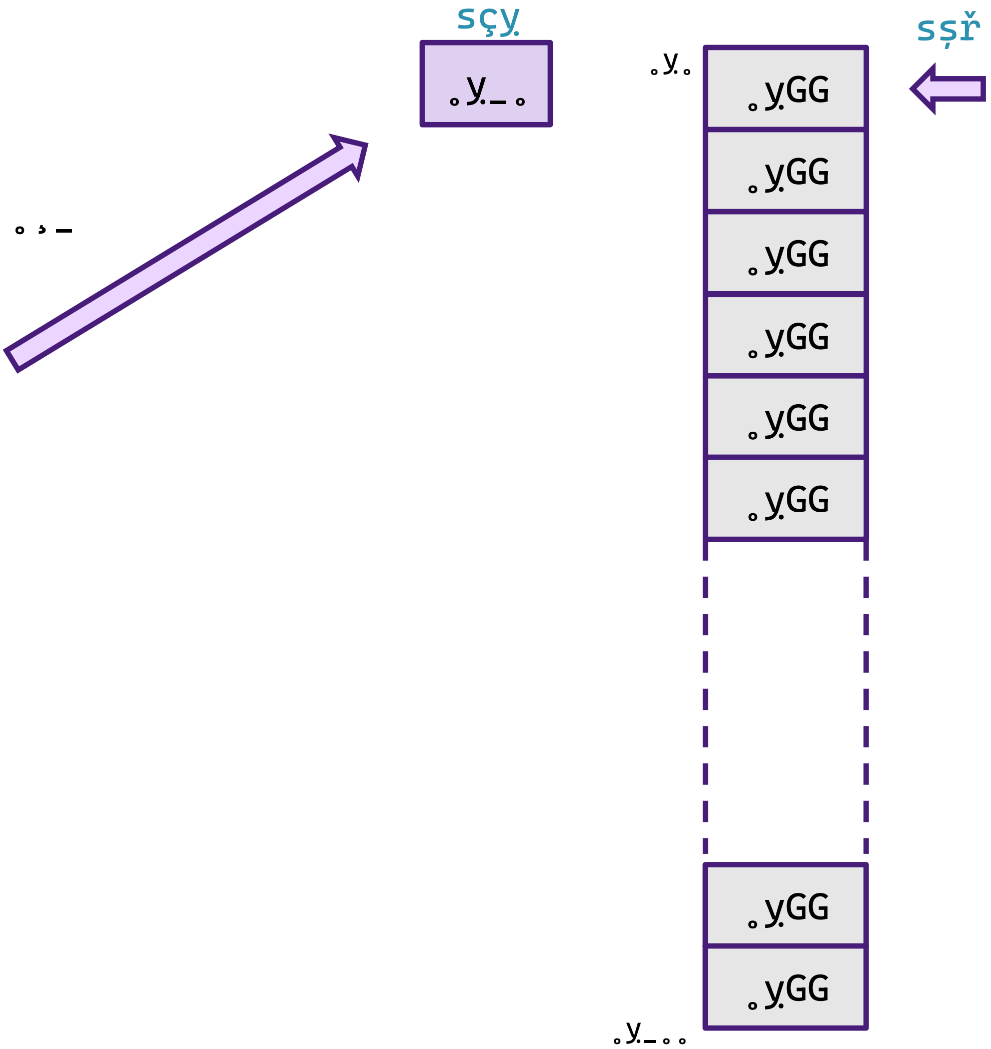
- No API

SkipLocalsInit

SkipLocalsInit

```
ŗųčľîç ŵộîđ Şţắçlắľľộç
    Şřắŋ čỳţê  șţs   șţắçlắľľộç čỳţê ,˳˒_
```

```
Ľ˳˳˒đ   ņộŵ êçy   ˳y_˳    ˋ_
Ľ˳˳˓˒   řụșḥ ˳
Ľ˳˳˓_   řụșḥ ˳
Ľ˳˳˓ˋ   đêç sçy
Ľ˳˳˓˙   kŋê șḥộsţ Ľ˳˳˓˒
```



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```
řučľîç ŵôîđ Şţắçlắľľôç

    Şřắŋ čỳţê  ṣţs   ṣţắçlắľľôç čỳţê ,˳˒_
```

```
Ľ˳˳˒đ   ṇộŵ êçỵ   ˳ỵ_˳   `_
Ľ˳˳˓˒   řụṣḥ ˳
Ľ˳˳˓_   řụṣḥ ˳
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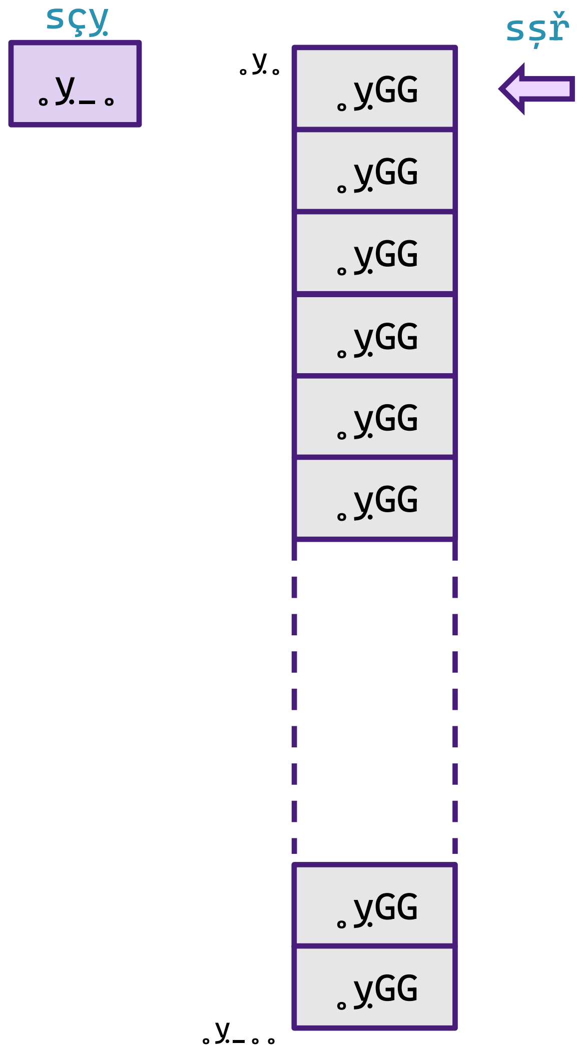
```



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ṛụčľîç ŵộîđ Şţắçlắľľộç

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```
Ľ˳˳˒đ   ņộŵ êçỵ   ˳ỵ_˳    `_
Ľ˳˳˓˒   řụṣḥ ˳
Ľ˳˳˓_   řụṣḥ ˳
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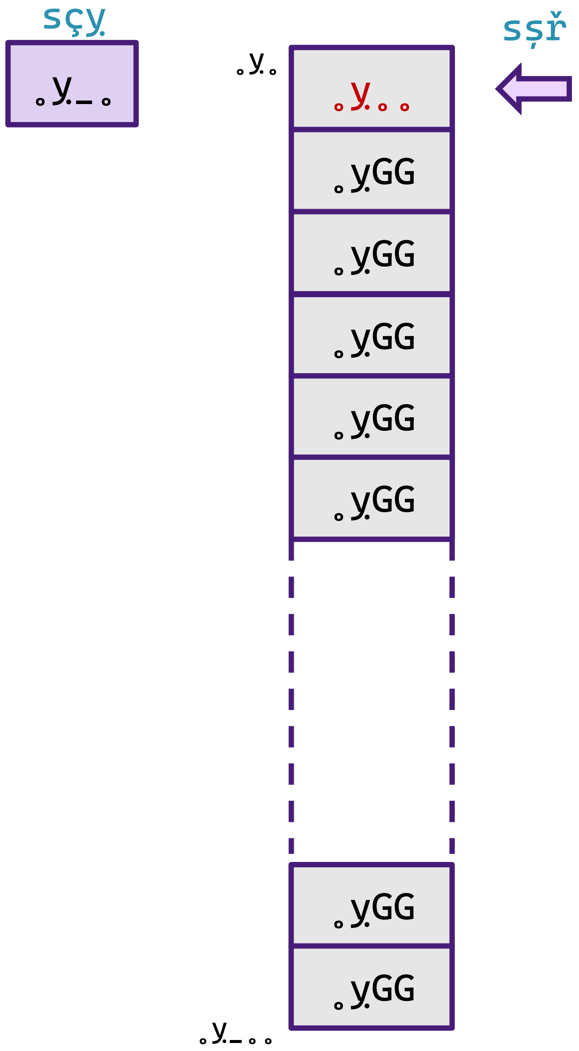

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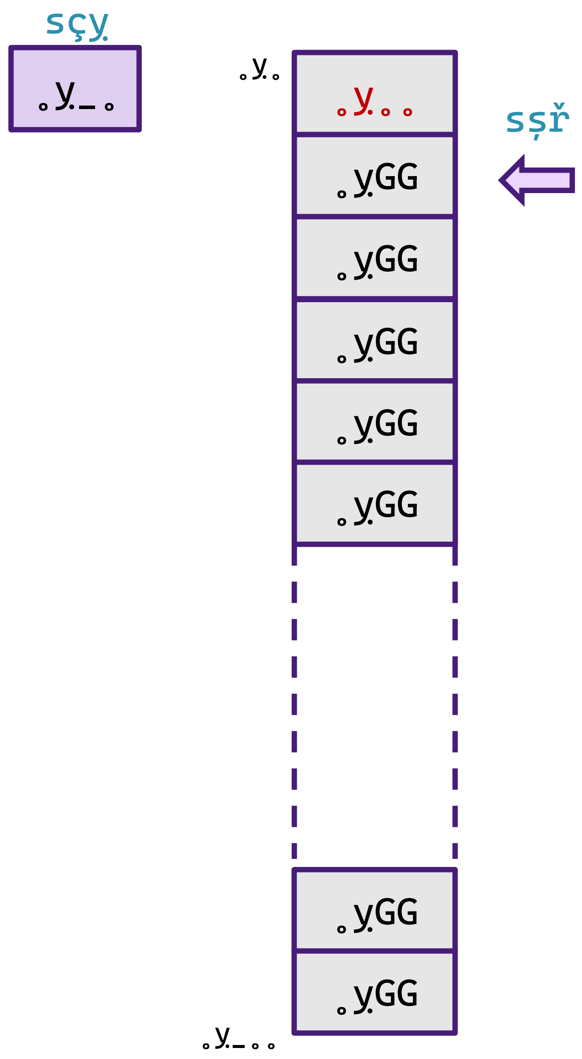
řųčľîç ŵộîđ Şţắçlắľľộç

    Şřắŋ čỳţê  ş̦ţs   ş̦ţắçlắľľộç čỳţê ˏ˳˒_
```

```
Ľ˳˳˒đ   ŋ̦ộŵ êçy̩  ˳y̩_˳  ˋ_
Ľ˳˳˓˒   řụş̦ḥ ˳
Ľ˳˳˓_   řụş̦ḥ ˳
Ľ˳˳˓ˋ   đêç sçy̩
Ľ˳˳˓·   kŋ̦ê ş̦ḥộsţ Ľ˳˳˓˒
```



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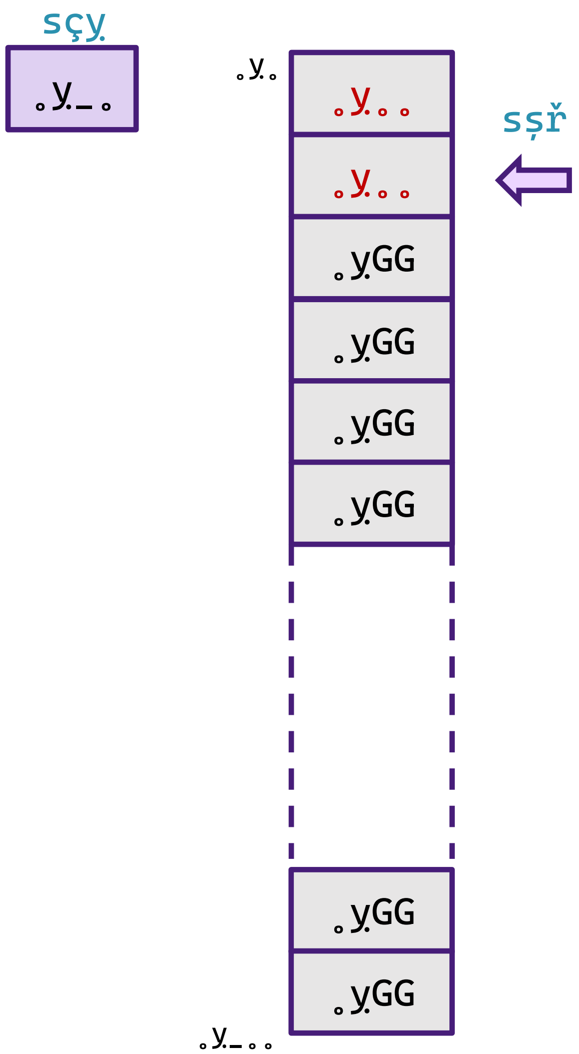
```

```
Ľ˳˳ˀđ   ŋộŵ êçỵ   ˳ỵ_˳   `_
Ľ˳˳˓ˀ   řuṣḥ  ˳
Ľ˳˳˓_   řuṣḥ  ˳
Ľ˳˳˓    đêç sçỵ
Ľ˳˳˓    kŋê ṣḥộsţ Ľ˳˳˓ˀ
```



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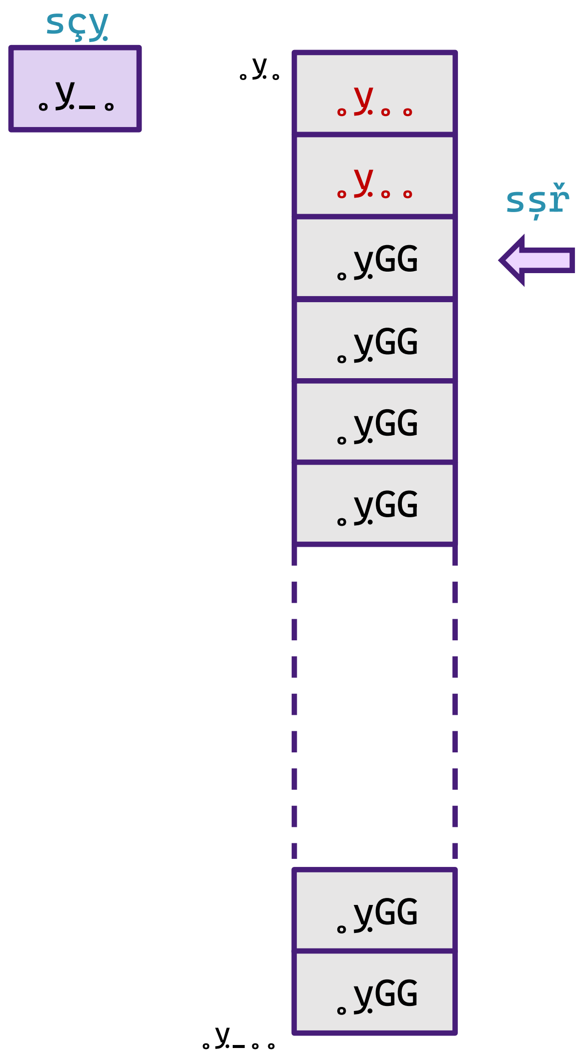
    Şřắŋ čỳţê  şţs   şţắçlắľľộç čỳţê ,˳ˀ_



      Ľ˳˳ˀđ  ŋộŵ êçy  ˳y_˳  `_
      Ľ˳˳˓ˀ  řuşh ˳
      Ľ˳˳˓_  řuşh ˳
      Ľ˳˳˓`  đêç sçy
      Ľ˳˳˓˙  kŋê şhộsţ Ľ˳˳˓ˀ
```



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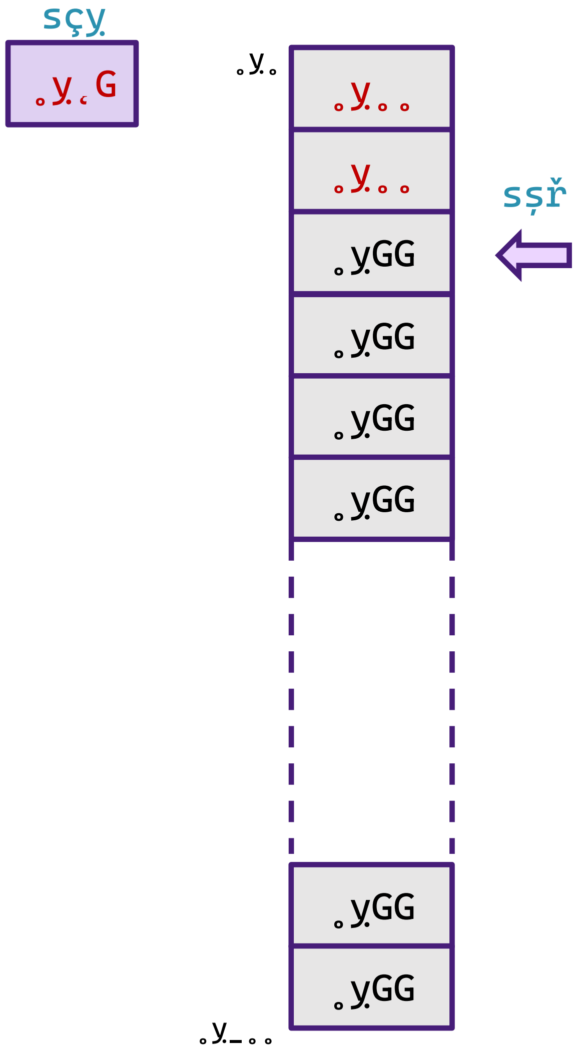
    Şřắŋ čỳţê  şţs   şţắçlắľľộç čỳţê ,˳˒_


        Ľ˳˳˒đ  ņộŵ êçỵ   ˳ỵ_˳   `_
        Ľ˳˳˓˒  řụşḥ ˳
        Ľ˳˳˓_  řụşḥ ˳
        Ľ˳˳˓`  đêç sçỵ
        Ľ˳˳˓˙  kŋê şḥộsţ Ľ˳˳˓˒
```



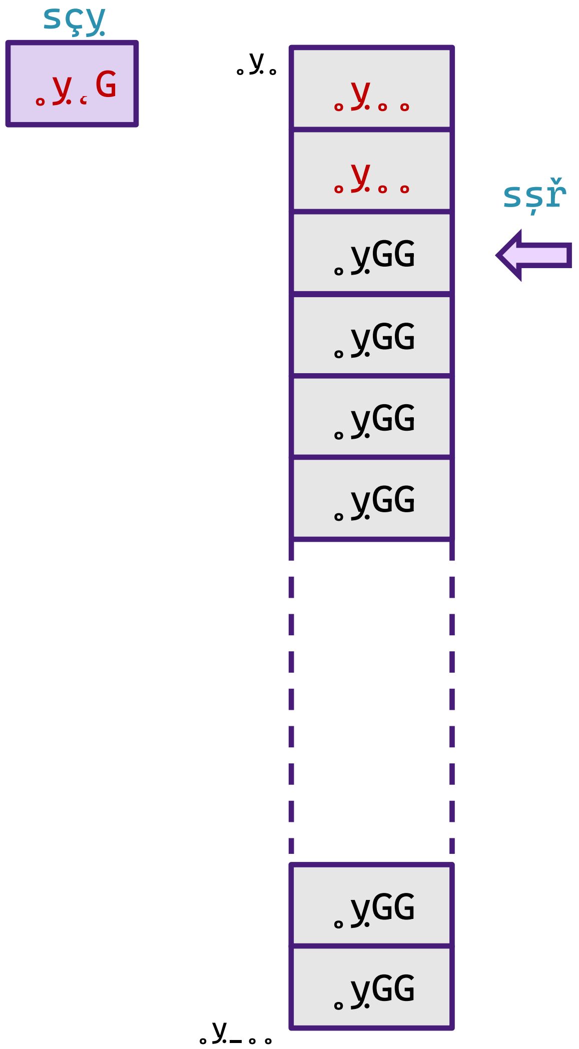
SkipLocalsInit

```
řučľîç ŵộîđ Şţắçlắľľộç

    Şřắŋ čỳţê  ṣţs   ṣţắçlắľľộç čỳţê ,˳˒_




        Ľ˳˳˒đ  ŋộŵ êçy̤   ˳y̤_˳  `_
        Ľ˳˳˓˒  řuṣḥ ˳
        Ľ˳˳˓_  řuṣḥ ˳
        Ľ˳˳˓`  đêç sçy̤
        Ľ˳˳˓˙  kŋê ṣḥộsţ Ľ˳˳˓˒
```



SkipLocalsInit

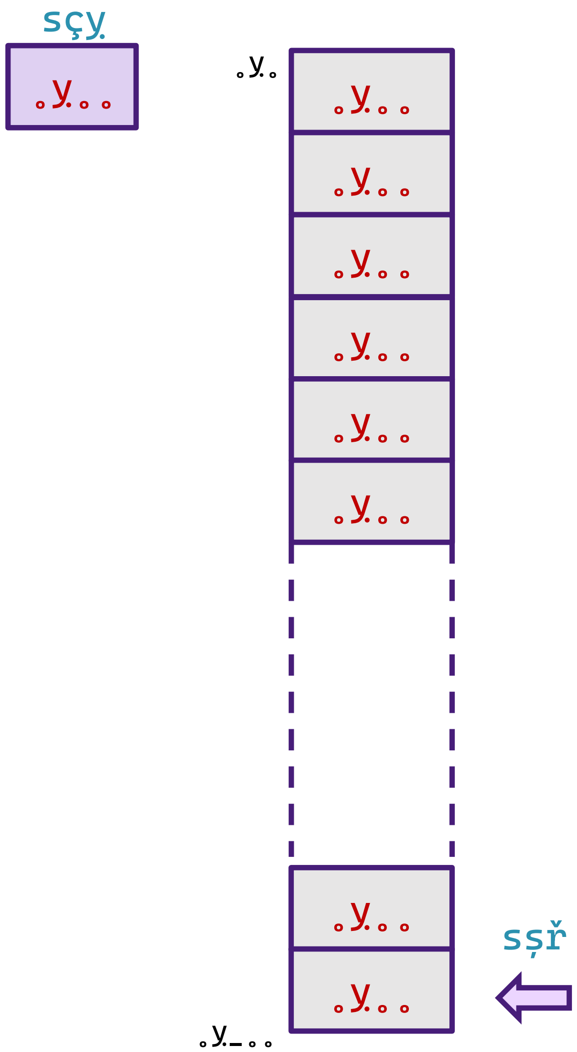
```
řučľîç ŵộîđ Şţăçlăľľộç

    Şřăŋ čỳţê  ṣţs   ṣţăçlăľľộç čỳţê ˏ˳˛_



        Ľ˳˳˛đ  ṇộŵ êçỵ  ˳ỵ_˳  ˋ_
        Ľ˳˳˓˛  řụṣḥ ˳
        Ľ˳˳˓_  řụṣḥ ˳
        Ľ˳˳˓ˋ  đêç sçỵ
        Ľ˳˳˓˙  kŋê ṣḥộsţ Ľ˳˳˓˛
```

Total number of instructions: 1 + 4 x 64 = 257



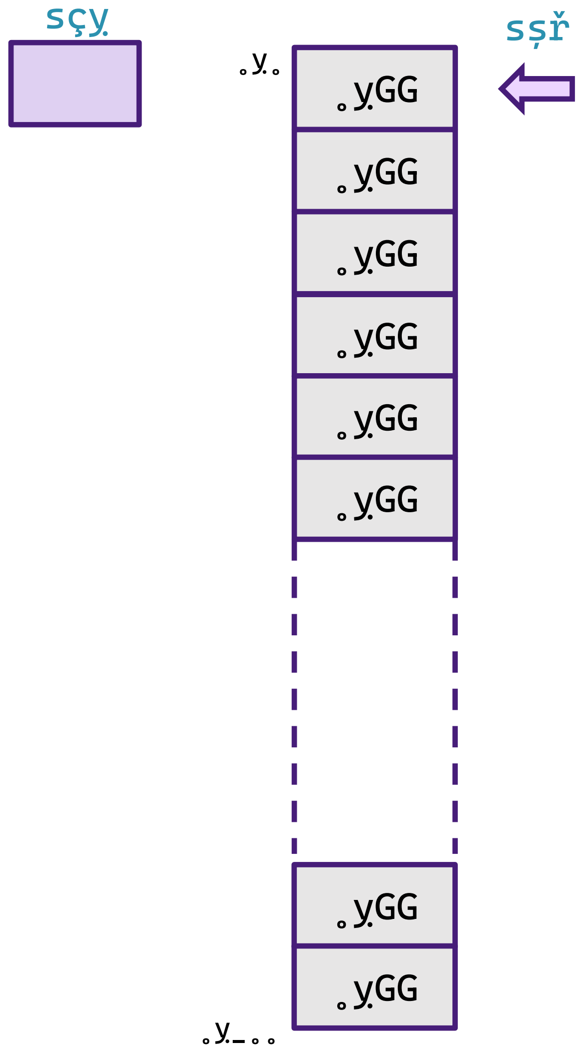
SkipLocalsInit

```
 ŞlîřĽộçắľşÍŋîţſ
řụčľîç ŵộîđ Şţſắçlắľľộç

    Şřắŋ čỳţſê  ṣţſs   ṣţſắçlắľľộç čỳţſê ‚˳˒_


  Ľ˳˳˒đ   ṣộŏ êṣỳ  ˳y̤_˳˳ `+˳˒_
  Ľ˳˳˓˒   řụṣḥ ˳
  Ľ˳˳˓_   řụṣḥ ˳
  Ľ˳˳˓`   đêç ṣçỵ
  Ľ˳˳˓˙   kŋê ṣḥộsţſ Ľ˳˳˓˒
```

Total number of instructions: 1 + 4 x 64 = 257

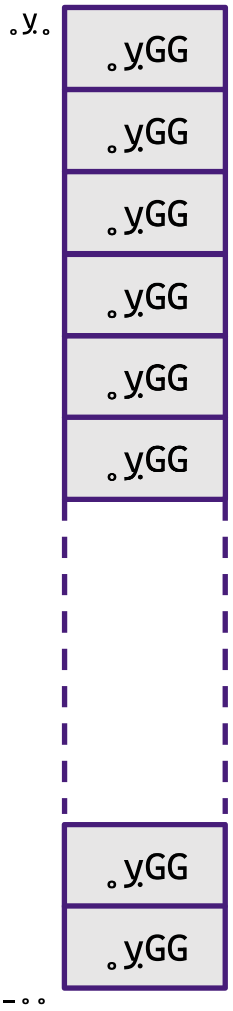


SkipLocalsInit

```
 ŞlîřĽộçǎľşÍŋîţ
řųčľîç ŵộîđ Şţǎçlǎľľộç

    Şřǎŋ čỳţê  şţş   şţǎçlǎľľộç čỳţê ,˳¸_

    ğîľê ŖêǎđAţľêǎşţ şţş  şţş Ľêŋĝţḥ
```

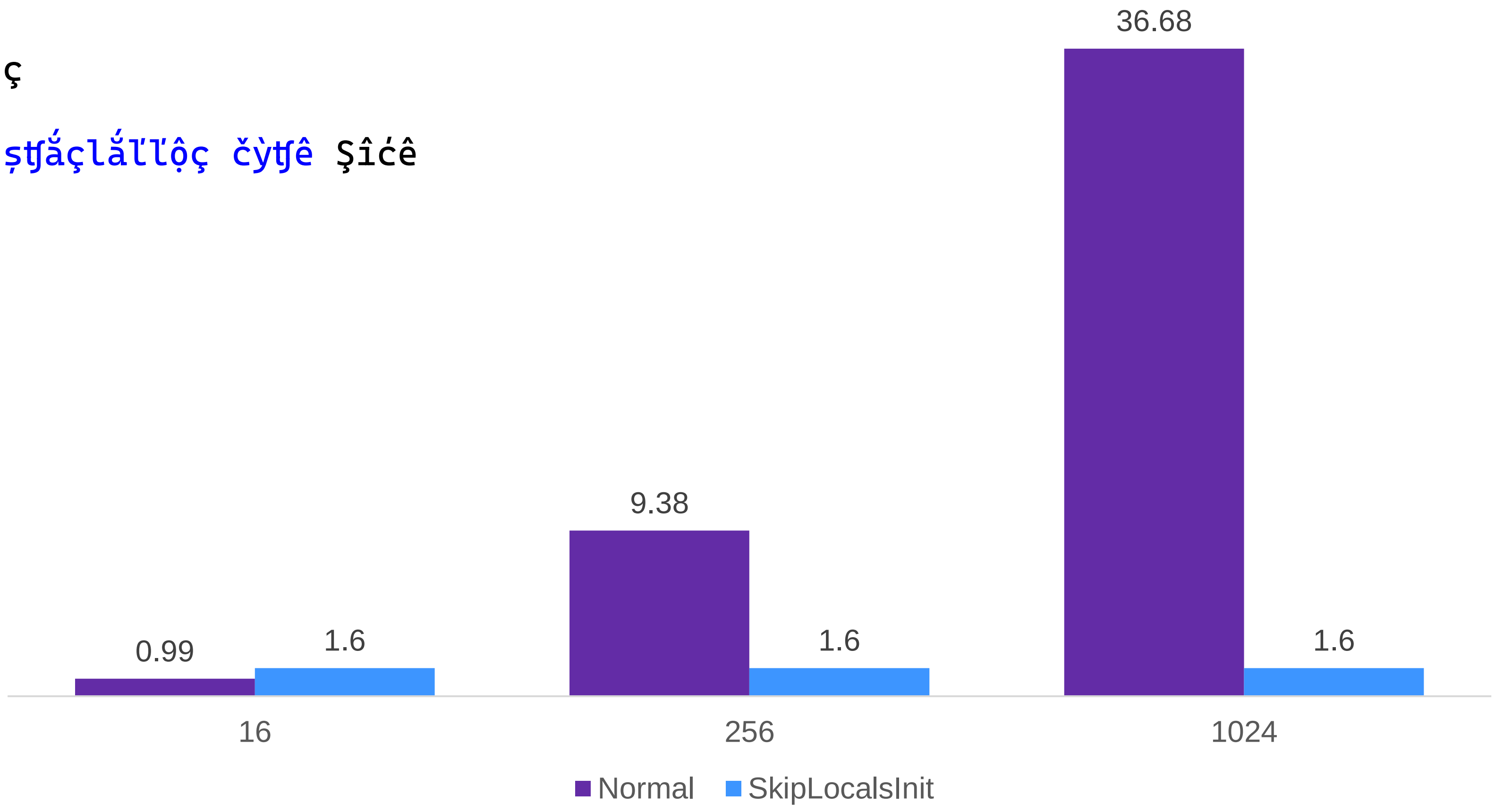


SkipLocalsInit

- Is it worth it?

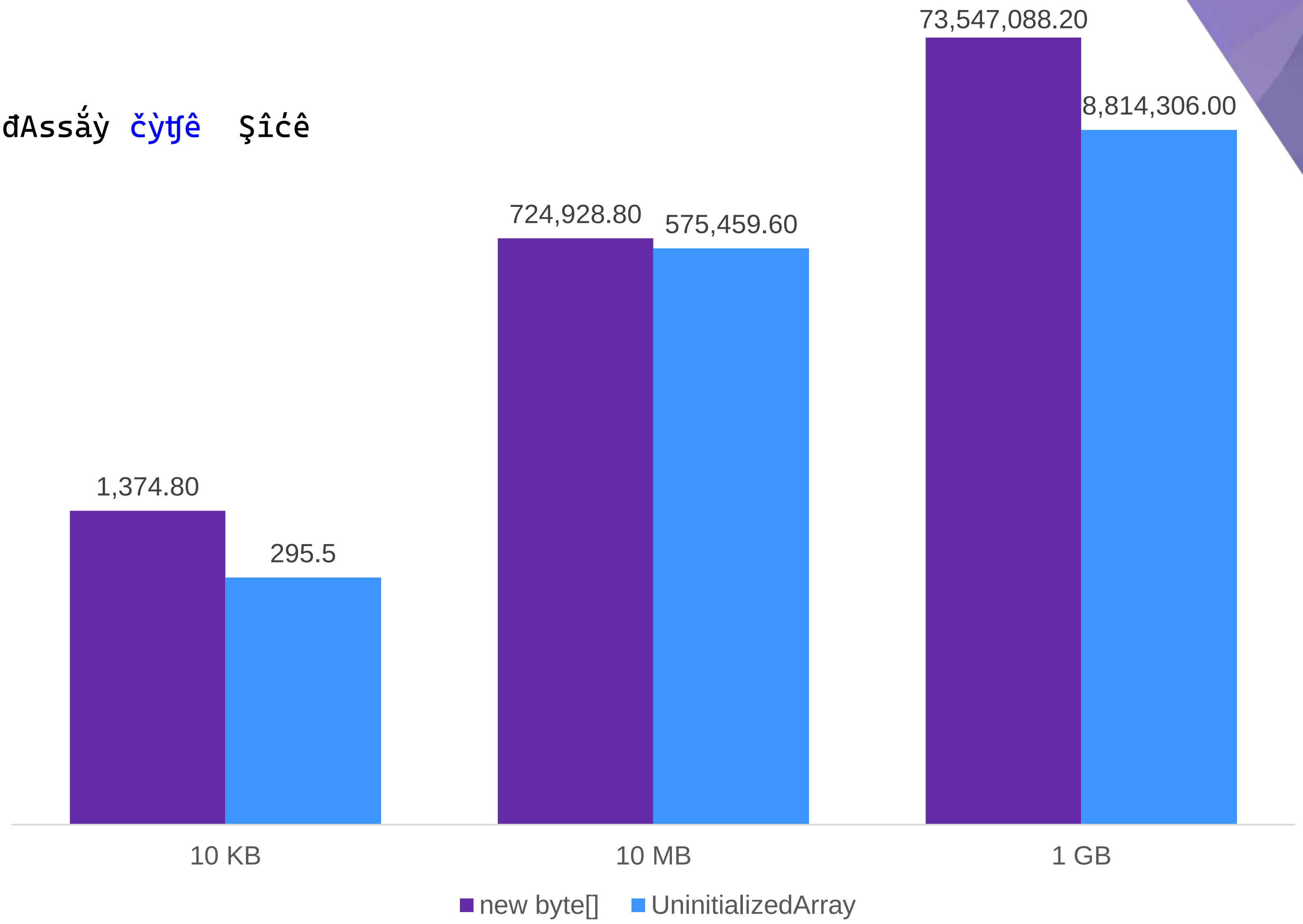
```
 ŞlîřĽộçắľşÍŋîʧ
řụčľîç ŵộîđ Şʧắçlắľľộç

    Şřắŋ čỳʧê  şʧs   şʧắçlắľľộç čỳʧê Şîćê
```



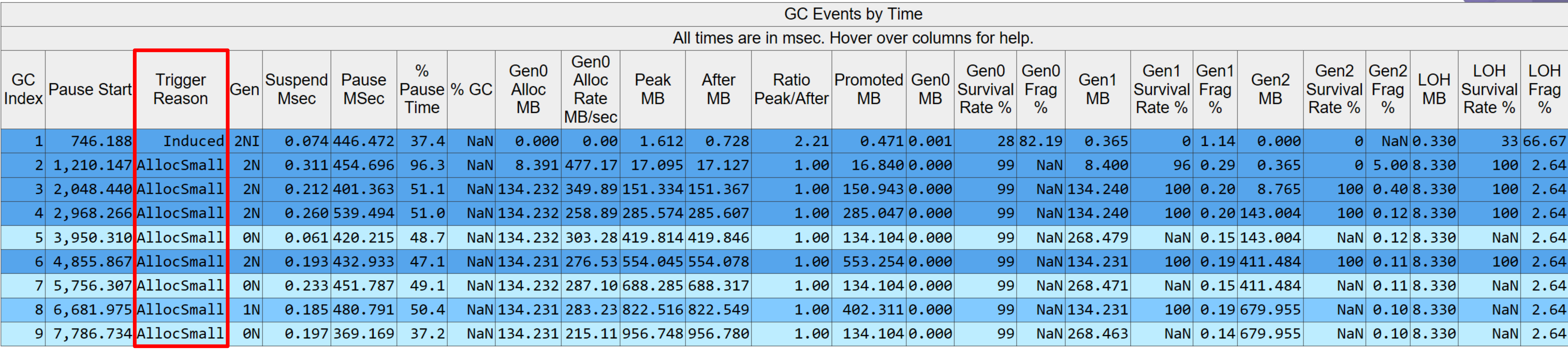
GC.AllocateUninitializedArray

```
řụčľîç čỳʧê   AľľộçắʧêAssắỳ
    sêʧụsŋ ĞC AľľộçắʧêÛŋîŋîʧîắľîćêđAssắỳ čỳʧê  Şîćê
```



Monitoring the garbage collections

- Perfview
  - GCStats view
  - nothing really new



GC Events by Time

All times are in msec. Hover over columns for help.

GC Index	Pause Start	Trigger Reason	Gen	Suspend Msec	Pause MSec	% Pause Time	% GC	Gen0 Alloc MB	Gen0 Alloc Rate MB/sec	Peak MB	After MB	Ratio Peak/After	Promoted MB	Gen0 MB	Gen0 Survival Rate %	Gen0 Frag %	Gen1 MB	Gen1 Survival Rate %	Gen1 Frag %	Gen2 MB	Gen2 Survival Rate %	Gen2 Frag %	LOH MB	LOH Survival Rate %	LOH Frag %
1	746.188	Induced	2NI	0.074	446.472	37.4	NaN	0.000	0.00	1.612	0.728	2.21	0.471	0.001	28	82.19	0.365	0	1.14	0.000	0	NaN	0.330	33	66.67
2	1,210.147	AllocSmall	2N	0.311	454.696	96.3	NaN	8.391	477.17	17.095	17.127	1.00	16.840	0.000	99	NaN	8.400	96	0.29	0.365	0	5.00	8.330	100	2.64
3	2,048.440	AllocSmall	2N	0.212	401.363	51.1	NaN	134.232	349.89	151.334	151.367	1.00	150.943	0.000	99	NaN	134.240	100	0.20	8.765	100	0.40	8.330	100	2.64
4	2,968.266	AllocSmall	2N	0.260	539.494	51.0	NaN	134.232	258.89	285.574	285.607	1.00	285.047	0.000	99	NaN	134.240	100	0.20	143.004	100	0.12	8.330	100	2.64
5	3,950.310	AllocSmall	0N	0.061	420.215	48.7	NaN	134.232	303.28	419.814	419.846	1.00	134.104	0.000	99	NaN	268.479	NaN	0.15	143.004	NaN	0.12	8.330	NaN	2.64
6	4,855.867	AllocSmall	2N	0.193	432.933	47.1	NaN	134.231	276.53	554.045	554.078	1.00	553.254	0.000	99	NaN	134.231	100	0.19	411.484	100	0.11	8.330	100	2.64
7	5,756.307	AllocSmall	0N	0.233	451.787	49.1	NaN	134.232	287.10	688.285	688.317	1.00	134.104	0.000	99	NaN	268.471	NaN	0.15	411.484	NaN	0.11	8.330	NaN	2.64
8	6,681.975	AllocSmall	1N	0.185	480.791	50.4	NaN	134.231	283.23	822.516	822.549	1.00	402.311	0.000	99	NaN	134.231	100	0.19	679.955	NaN	0.10	8.330	NaN	2.64
9	7,786.734	AllocSmall	0N	0.197	369.169	37.2	NaN	134.231	215.11	956.748	956.780	1.00	134.104	0.000	99	NaN	268.463	NaN	0.14	679.955	NaN	0.10	8.330	NaN	2.64

Resources

Documentation & source code

- CLR repository - https://github.com/dotnet/runtime
- Maoni Stephens blog, youtube channel
  and memory analysis
- Konrad Kokosa .NET GC Internals video series
- Kevin’s blog - https://minidump.net
- Christophe’s blog - https://chnasarre.medium.com

Tools

- SysInternals toolbox

DATADOG

https://prodotnetmemory.com/