TOWARDS SAFETY & SECURITY IN C++

Daniela Engert - Stockholm 2025

C-00000291*.sys

- security and safety
- safety in our code, or lack thereof
- existing solutions for improvement
- new features in C++26
- options for the future

ABOUT ME

- Electrical engineer
- Building computers and creating software for more than 40 years
- Developing hardware and software in the field of applied digital signal processing for more than 35 years

- Member of the C++ committee (a.k.a. WG21) for 5 years (EWG, SG15)

SOFTWARE VULNERABILITIES

- About 70 percent of Microsoft common vulnerabilities and exposures (CVEs) are memory safety vulnerabilities (based on 2006-2018 CVEs).[8]
- About 70 percent of vulnerabilities identified in Google's Chromium project are memory safety vulnerabilities.[9]
- In an analysis of Mozilla vulnerabilities, 32 of 34 critical/high bugs were memory safety vulnerabilities.[10]
- Based on analysis by Google's Project Zero team, 67 percent of zero-day vulnerabilities in 2021 were memory safety vulnerabilities.[11]

The Case for Memory Safe Roadmaps, 2023

2024 CWE Top 25

Rank	ID	Name	Score	CVEs in KEV	Rank Change vs. 2023
1	CWE-79	Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')	56.92	3	+1
2	CWE-787	Out-of-bounds Write	45.20	18	-1
3	CWE-89	Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')	35.88	4	0
4	CWE-352	Cross-Site Request Forgery (CSRF)	19.57	0	+5
5	CWE-22	Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal')	12.74	4	+3
6	CWE-125	Out-of-bounds Read	11.42	3	+1
7	CWE-78	Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')	11.30	5	-2
8	CWE-416	Use After Free	10.19	5	-4
9	CWE-862	Missing Authorization	10.11	0	+2
10	CWE-434	Unrestricted Upload of File with Dangerous Type	10.03	0	0
11	CWE-94	Improper Control of Generation of Code ('Code Injection')	7.13	7	+12
12	CWE-20	Improper Input Validation	6.78	1	-6
13	CWE-77	Improper Neutralization of Special Elements used in a Command ('Command Injection')	6.74	4	+3
14	CWE-287	Improper Authentication	5.94	4	-1
15	CWE-269	Improper Privilege Management	5.22	0	+7
16	CWE-502	Deserialization of Untrusted Data	5.07	5	-1
17	CWE-200	Exposure of Sensitive Information to an Unauthorized Actor	5.07	0	+13
18	CWE-863	Incorrect Authorization	4.05	2	+6
19	CWE-918	Server-Side Request Forgery (SSRF)	4.05	2	0
20	CWE-119	Improper Restriction of Operations within the Bounds of a Memory Buffer	3.69	2	-3
21	CWE-476	NULL Pointer Dereference	3.58	0	-9
22	CWE-798	Use of Hard-coded Credentials	3.46	2	-4
23	CWE-190	Integer Overflow or Wraparound	3.37	3	-9
24	CWE-400	Uncontrolled Resource Consumption	3.23	0	+13
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[redacted] now

[redacted]

(@[redacted]@pony.social

[redacted]

memory unsafety may cause a lot of software crashes, but it also helps a lot of people jailbreak their game consoles, so, it;s impossible to say if its bad or not,

Somewhere on Mastodon...

IN REAL LIFE ...


SECURITY


SECURITY


GMH Prüftechnik


FUNCTIONAL
SAFETY


FUNCTIONAL
SAFETY


GOING DOWN ...

```cpp
// contents of f.cpp

#include "f.h"

S s;
U u;

constexpr int f() {
    int *sp = s.b;
    int *sq = &s.b[0];
    int *sr = &s.b[4];
    int *st = &s.c;

    assert( sp ==  sq);
    assert( sr ==  st);
    assert(*sr == *st);

    int *up = u.b;
    int *uq = &u.b[0];
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https://godbolt.org/z/Tc13f7YbT

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constexpr int f() {
    S s;          // objects 's', 'u' uninitialized
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    int *sp = s.b;
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    int *st = &s.c;

    assert( sp ==  sq);
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    assert(*sr == *st); // GCC may complain about UB
     // erroneous behaviour (EB) 🚀 in C++26 💥🛡️
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// contents of f.cpp

#include "f.h"

constexpr int f() {
    S s{};          // initialized now, {} from C++11
    U u{};          // recommended best practice 👍
                    // ⇒ no longer UB or EB ⇒ 🎉
    int *sp = s.b;
    int *sq = &s.b[0];
    int *sr = &s.b[4];
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    assert( sp ==  sq);
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https://godbolt.org/z/Trzo7rcPG

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The current C++ standard document mentions "undefined behaviour" (UB) ≈ 90 times in the language-specific part.


This is fine.

Constant evaluation

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[defns.undefined], [expr.const]/10

CONSTEXPR

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new in C++26:

- exceptions
- placement new
- structured bindings
- improved references
- lots more library functions


MORE CODE ...

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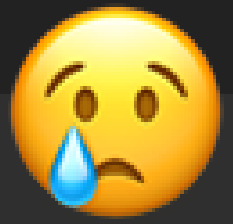
1  constexpr int f(const int *array, bool a, bool b) {
2      unsigned index = 1;
3
4      if (a) --index;
5      if (b) --index;
6
7      return array[index];
8  }
9
10 constexpr int array[4]{};
11
12 static_assert(f(array, false, false) == 0);
```



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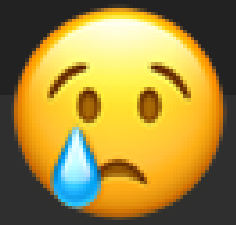

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5      if (b) --index;
6
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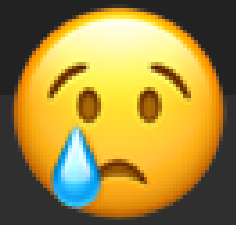

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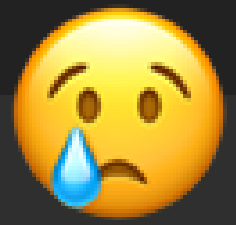

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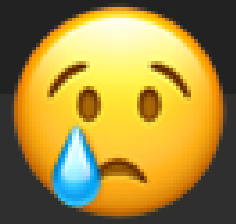

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 1 constexpr int f(const int (&array)[4], bool a, bool b) {
 2     unsigned index = 1;
 3
 4     if (a) --index;
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 6
 7     // perform a range check here!
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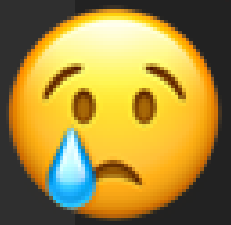

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#include <span>  // "Contemporary C++" -> use strong types

constexpr int select(std::span<const int> sequence,
                     SomeBooleanOption a, AnotherBooleanOption b) {
    unsigned index = 1;

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    // !!! perform a range check here !!!
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constexpr int select(std::span<const int> sequence,
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    unsigned index = 1;

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    // range checking is internally done
    // in a 'hardened' standard library!
    return sequence[index];
}

constexpr int array[4]{};

static_assert(select(array, option_a, option_b) == 0);
```

P3471

Standard library hardening

P3471

Standard library hardening

Expect this even before C++26 !

Louis Dionne "Security in C++", C++Now 2024

C++ library preconditions

- are either checked with termination semantics in all compilation modes,
- or are ignored → UB (status quo)

- detected contract violations
  - may stop execution instantly (without P2900)
  - detour to handle_contract_violation (with P2900)

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C++ standard library implementations may go beyond P3471

- more containers
- more classes
- more functions

- destructor pointer tombstones → resist "use after free" 😎 🛡️

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Available in MS-STL, libc++, ... !

```cpp
import std;

int main(int argc, char*[]) {
    std::println("hardened STL: {}", static_cast<bool>(_MSVC_STL_HARDENING));

    std::vector v(std::max(argc, 1), argc);
    std::println("v[3]  = {}", v[3]);
    std::println("v[-1] = {}", v[-1]);
}
```

MS-STL version 202502

just as ever

with hardening

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> cl test.cpp
> test.exe
hardened STL: false
v[3]  = 9673
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// program ended with return value 0
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with hardening

```
> cl test.cpp
> test.exe
hardened STL: true

// program execution stopped here
// with error code 0xC0000409
// i.e. STATUS_FAIL_FAST_EXCEPTION
```


DILIGENCE

P2900

Contracts for C++

P2900

Contracts for C++

Similar to Eiffel, Ada, or D

CONTRACTS IN C++

Support Developers

CONTRACTS IN C++

Assist "Design by Contract"

CONTRACTS IN C++

Check Correctness

```
1  // somewhere in the program source
2
3  int func(int x)
4  // precondition:  x is not 1
5  // postcondition: result value is different from argument value
6  {
7  // ...
8      assert(x != 3);  // assures an expectation
9  // ...
10     return x | 2;
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13 void call_func() {
14     func(0);    // fine
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int func(int x)           // function parameters are *immutable* in pre/post assertions!
    pre (x != 1)          // a precondition assertion
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// ------------------------------------------------------------------------------

// in global namespace, global module, invisible to users

// called on any contract violation
// system-provided or optionally user-replaceable

void handle_contract_violation(std::contracts::contract_violation cvo) {
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CONTRACT EVALUATION SEMANTICS

Semantics	check condition	fail → invoke handler	terminate
ignore (zero overhead)	❌	❌	❌
observe	✅	✅ [1]	❌
enforce	✅	✅	✅ [2]
quick_enforce	✅	❌	✅ [3]

[1] runtime: proceed after calling the handler / compile-time: diagnostic

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SAFE C++ ?

P3081

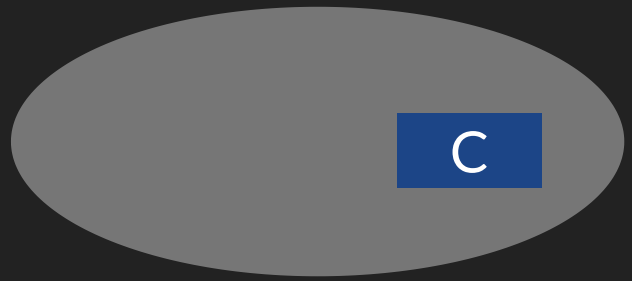
Core safety profiles for C++26

P3081

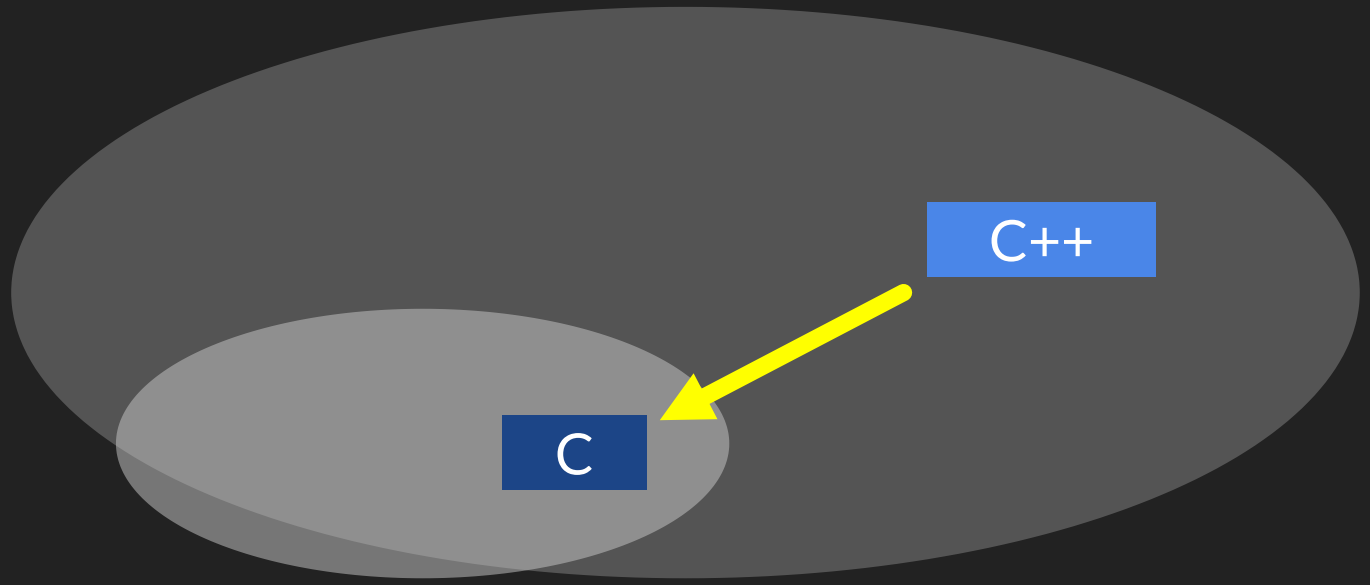
Core safety profiles for C++26

Not in C++26 ! 😬

THE IDEA



THE IDEA



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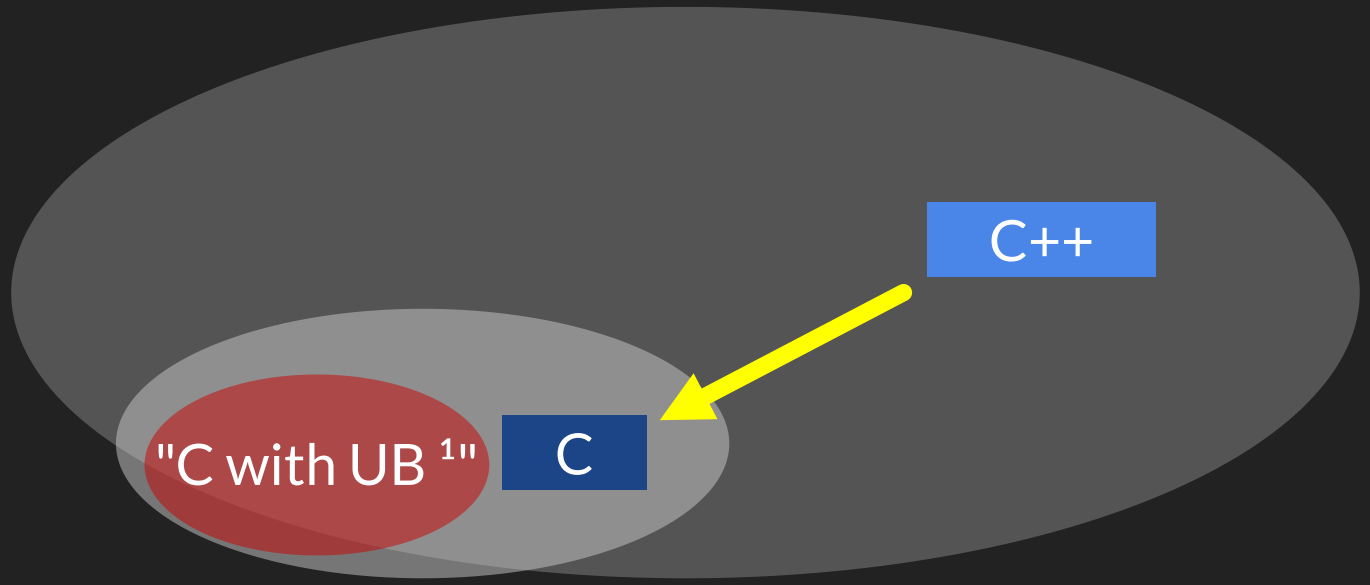

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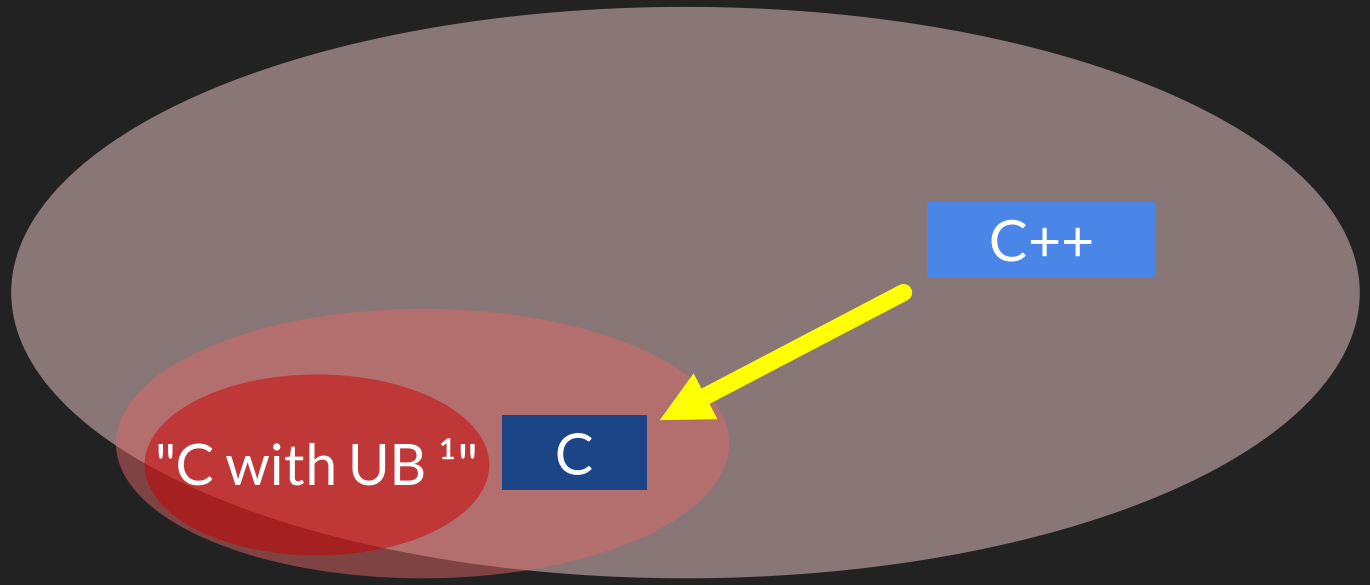
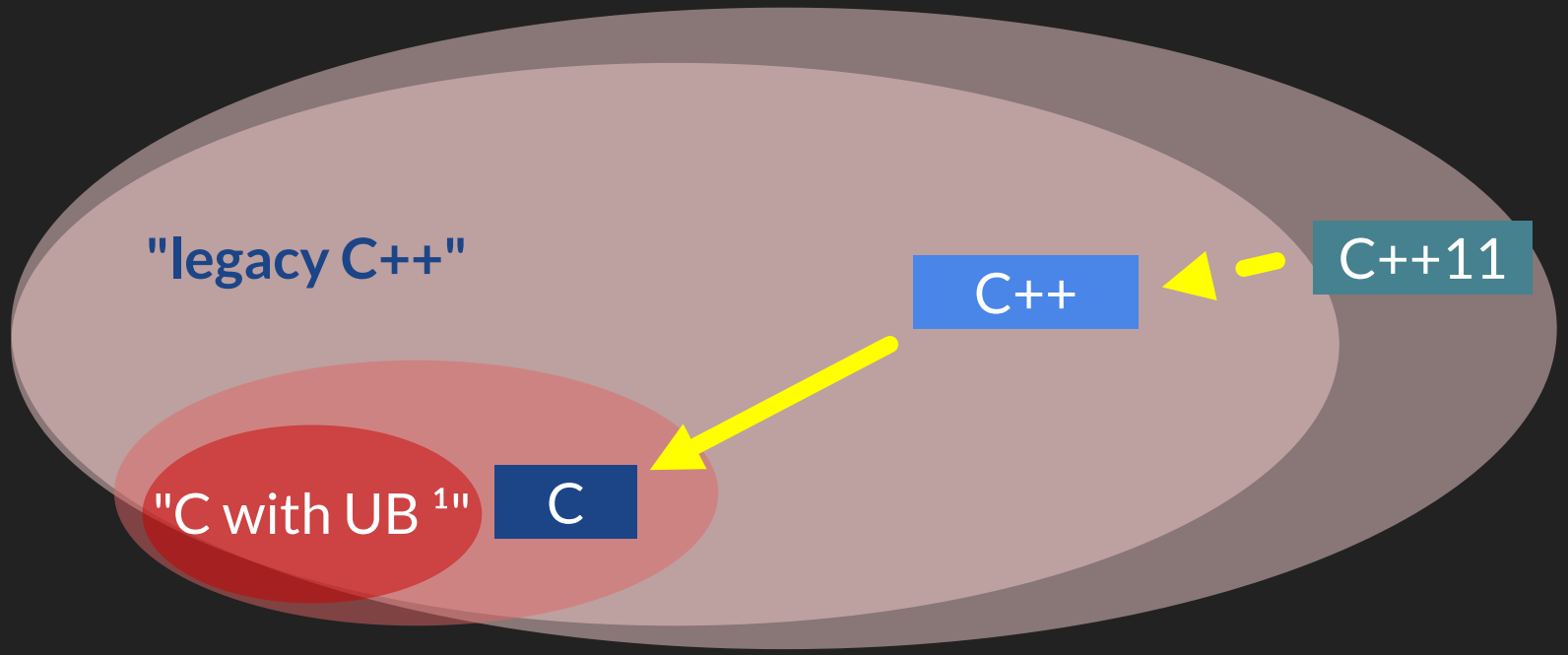


[1] WG14 N3453: C contains

- 100 cases of UB in the core language
- 221 cases of UB in total

THE IDEA



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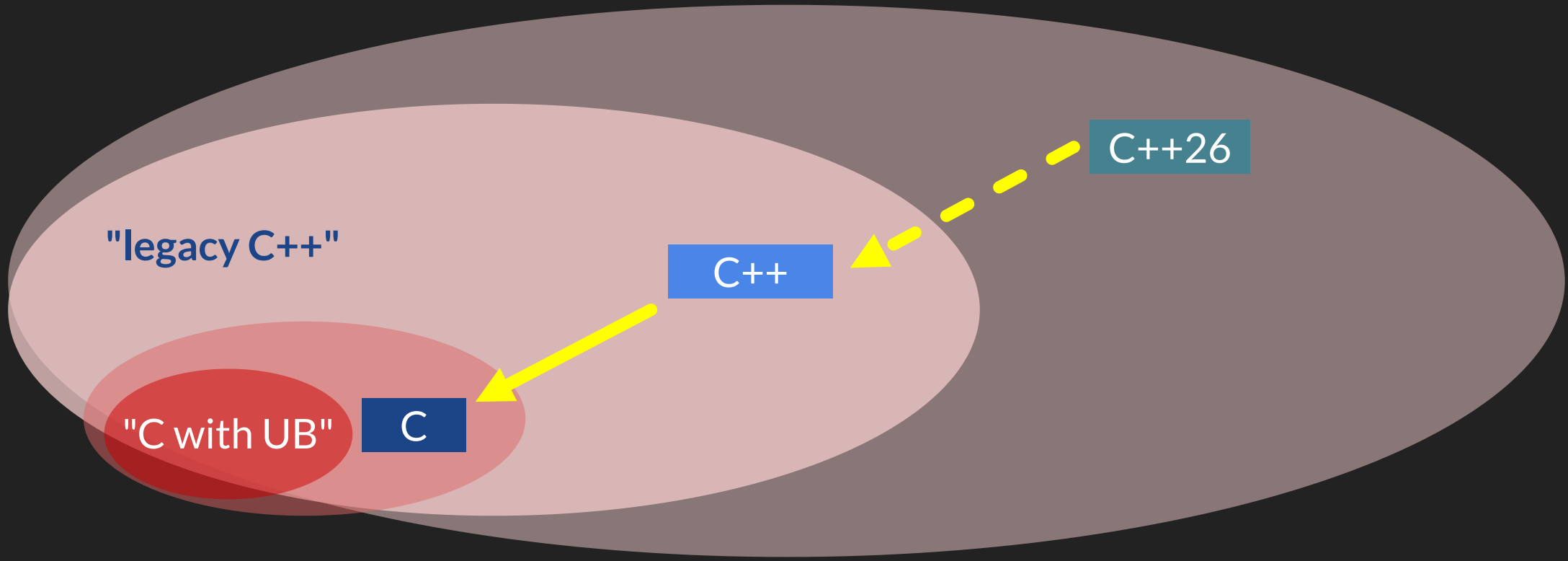
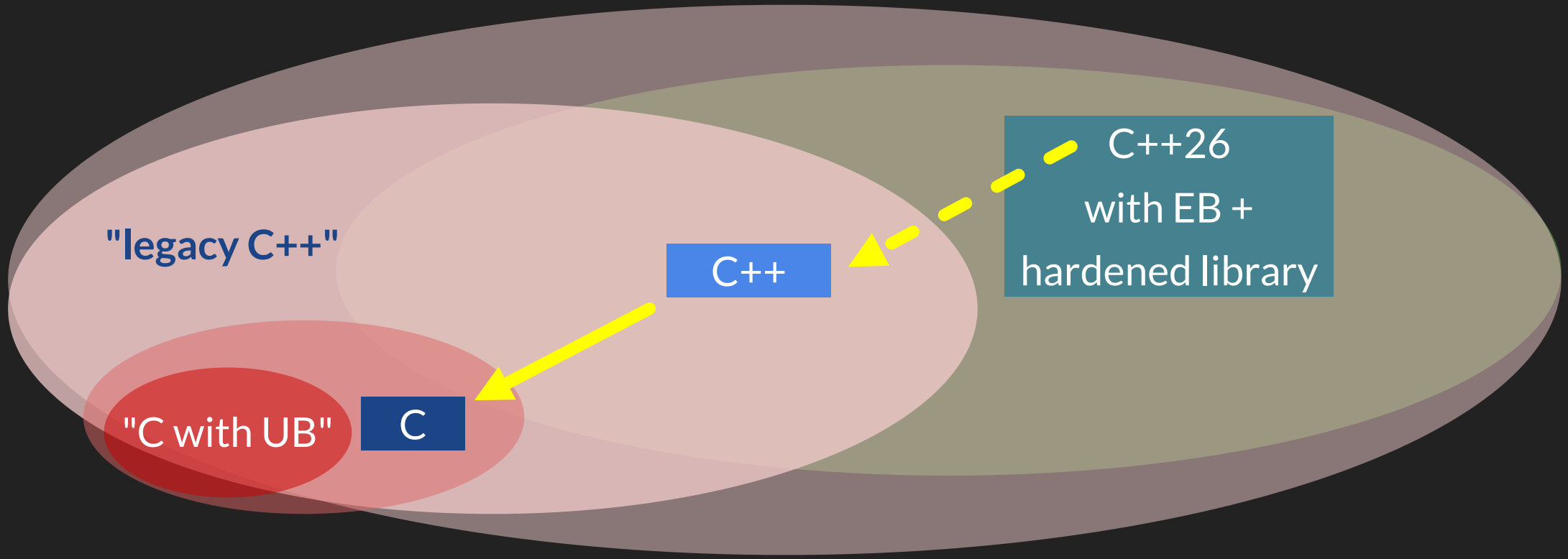


Inherited UB taints the entire language

C++ adds its own UB

THE IDEA



Inherited UB taints the entire language

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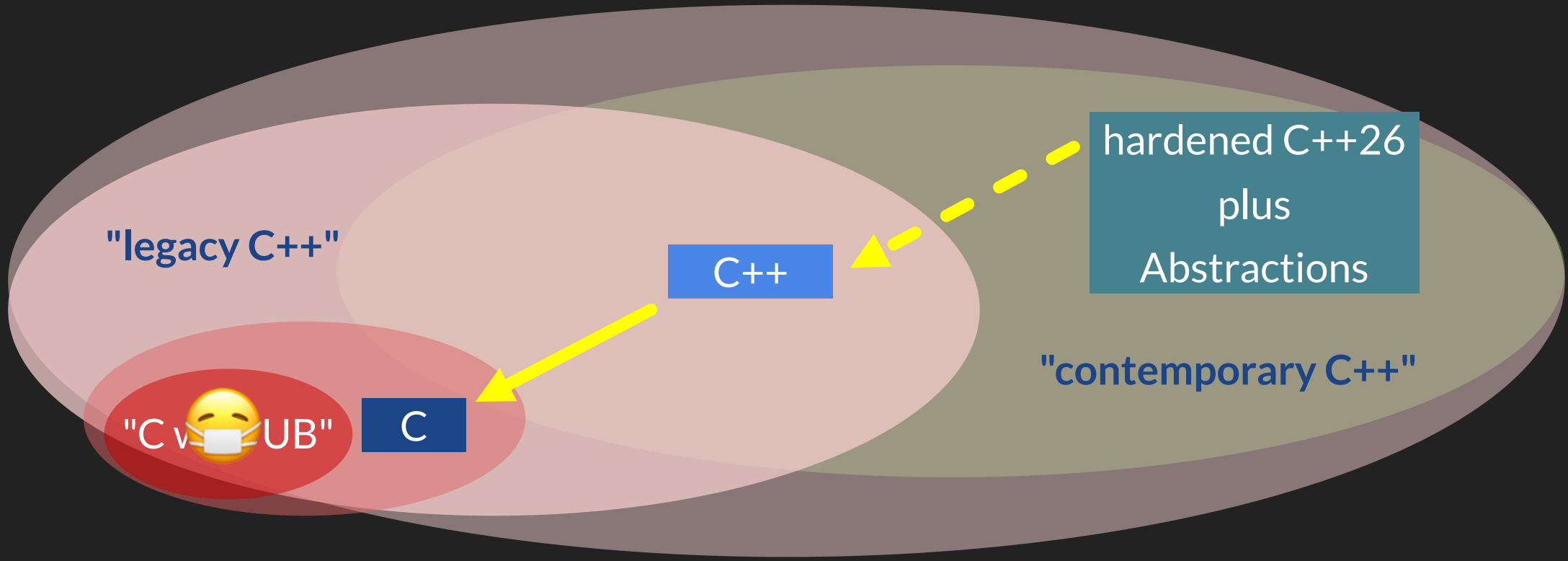

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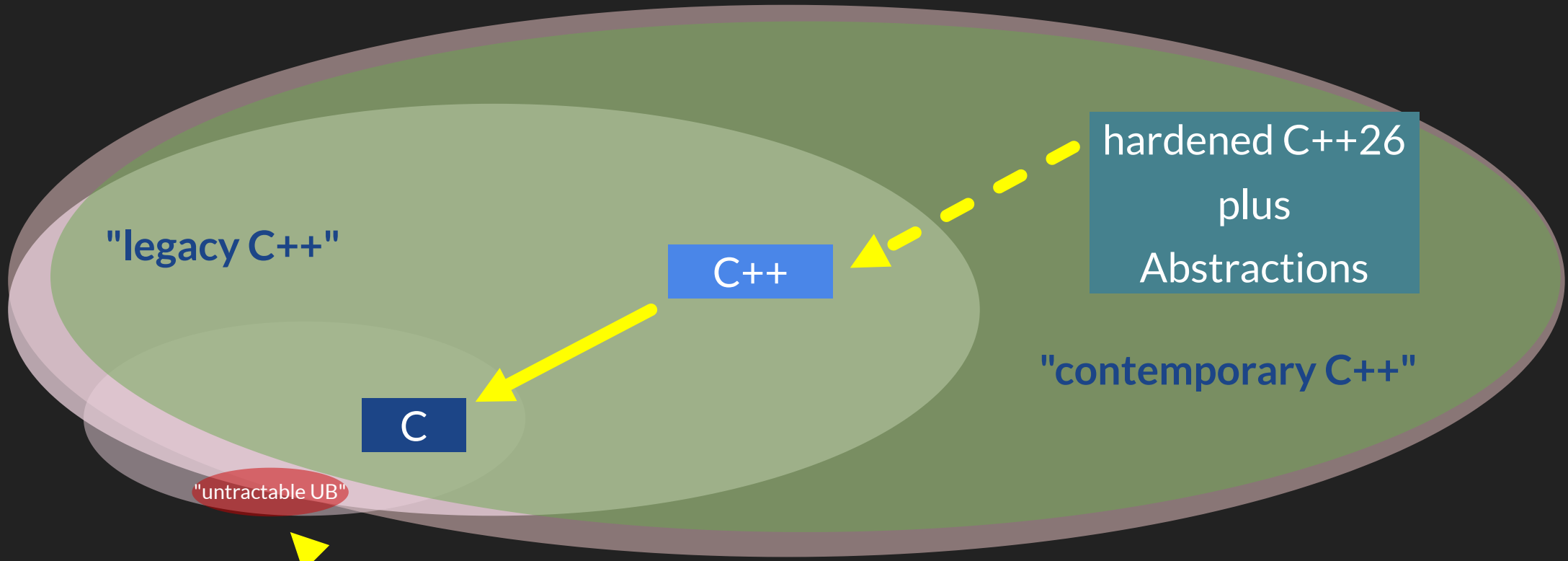


```
[[profiles::enforce(std::type)]];
[[profiles::enforce(std::bounds)]];
[[profiles::enforce(...)]];
```

BEYOND C++26

This will be pursued in a Whitepaper along with EB, Contracts, Profiles

SUMMARY

- why this perceived push towards security?
- security versus functional safety
- implications of UB at runtime and compile-time
- compile-time testing
- hardening the C++ standard library
- C++ contracts
- C++ profiles
- path into the future

"Simplicity is prerequisite for reliability"

Edsger W. Dijkstra

RESOURCES

- Living, up-to-date C++ standard (currently at C++26 Committee Draft)
- The Case for Memory Safe Roadmaps
- P2900 Contracts for C++
- P3081 Core safety profiles for C++26
- P3589 C++ Profiles: The Framework

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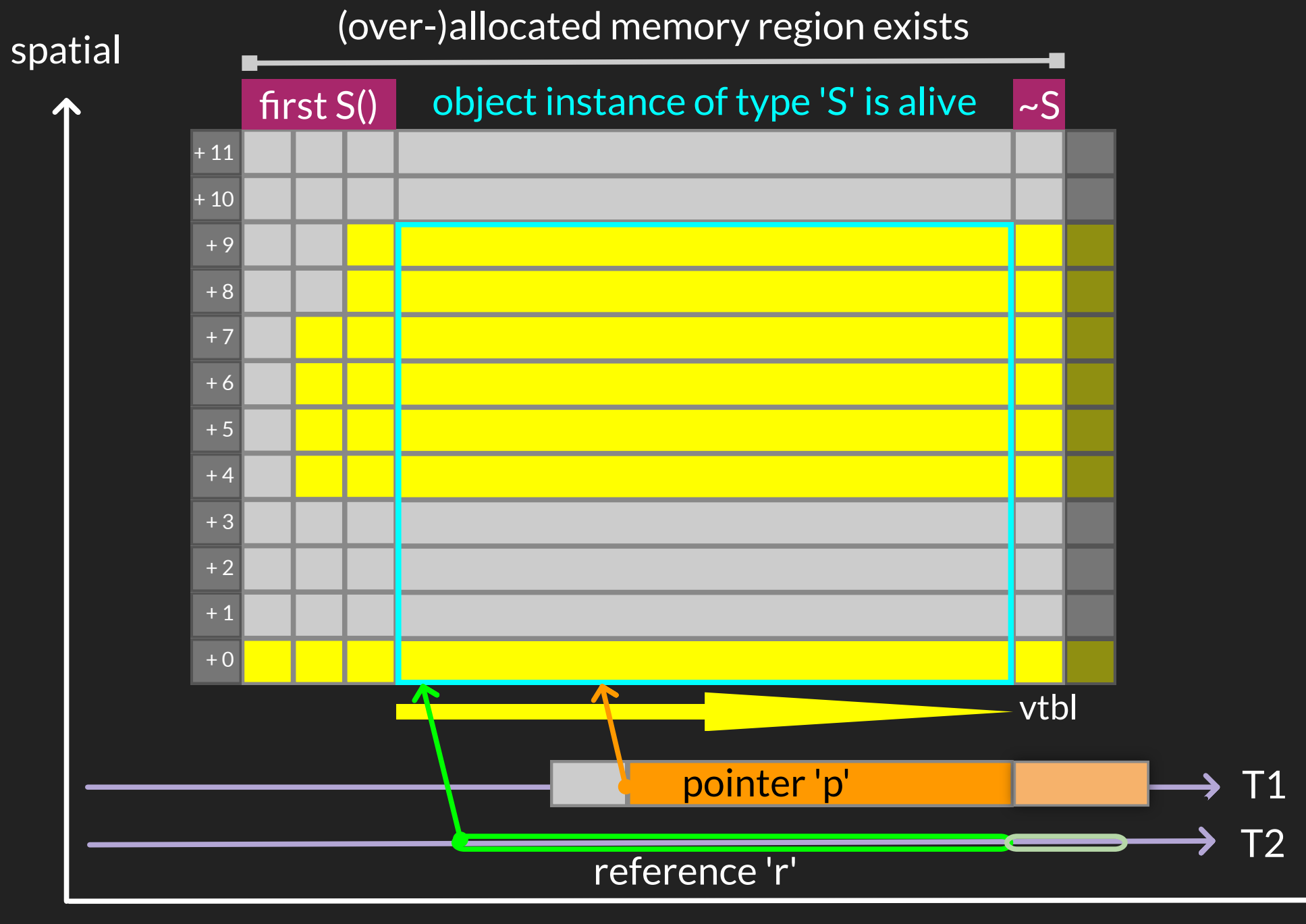
Ceterum censeo ABI esse frangendam


DEFINITIONS

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2    S();
3    virtual ~S();
4
5    char    a = 1;
6    int32_t b = 2;
7    int16_t c = 3;
8  };
9
10 auto _ = new S;
11
12 void Thread1 {
13   S * p;
14   ...
15   p = _;
16   ...
17 }
18
19 void Thread2 {
20   ...
21   S & r = *_;
22   ...
23 }
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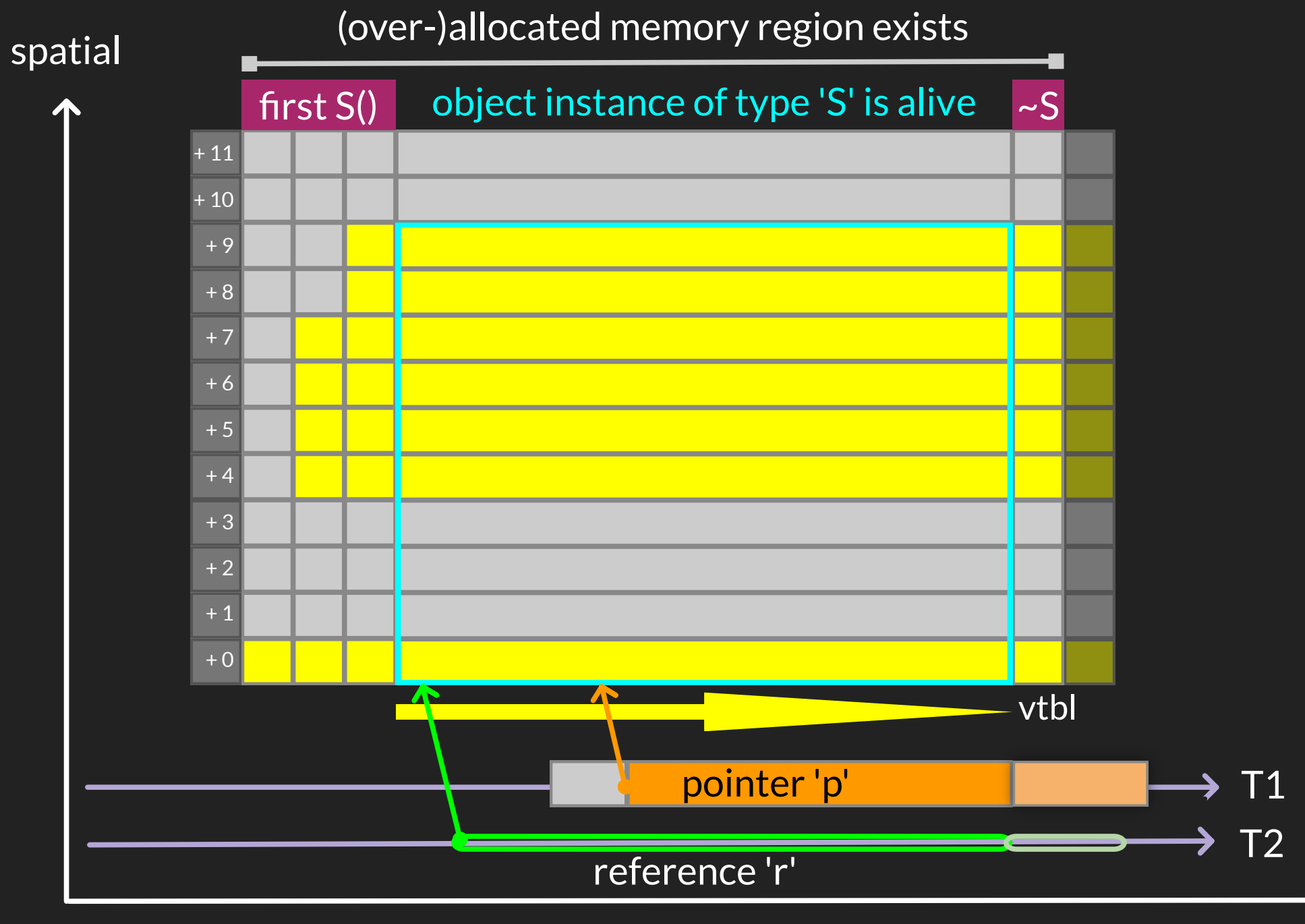


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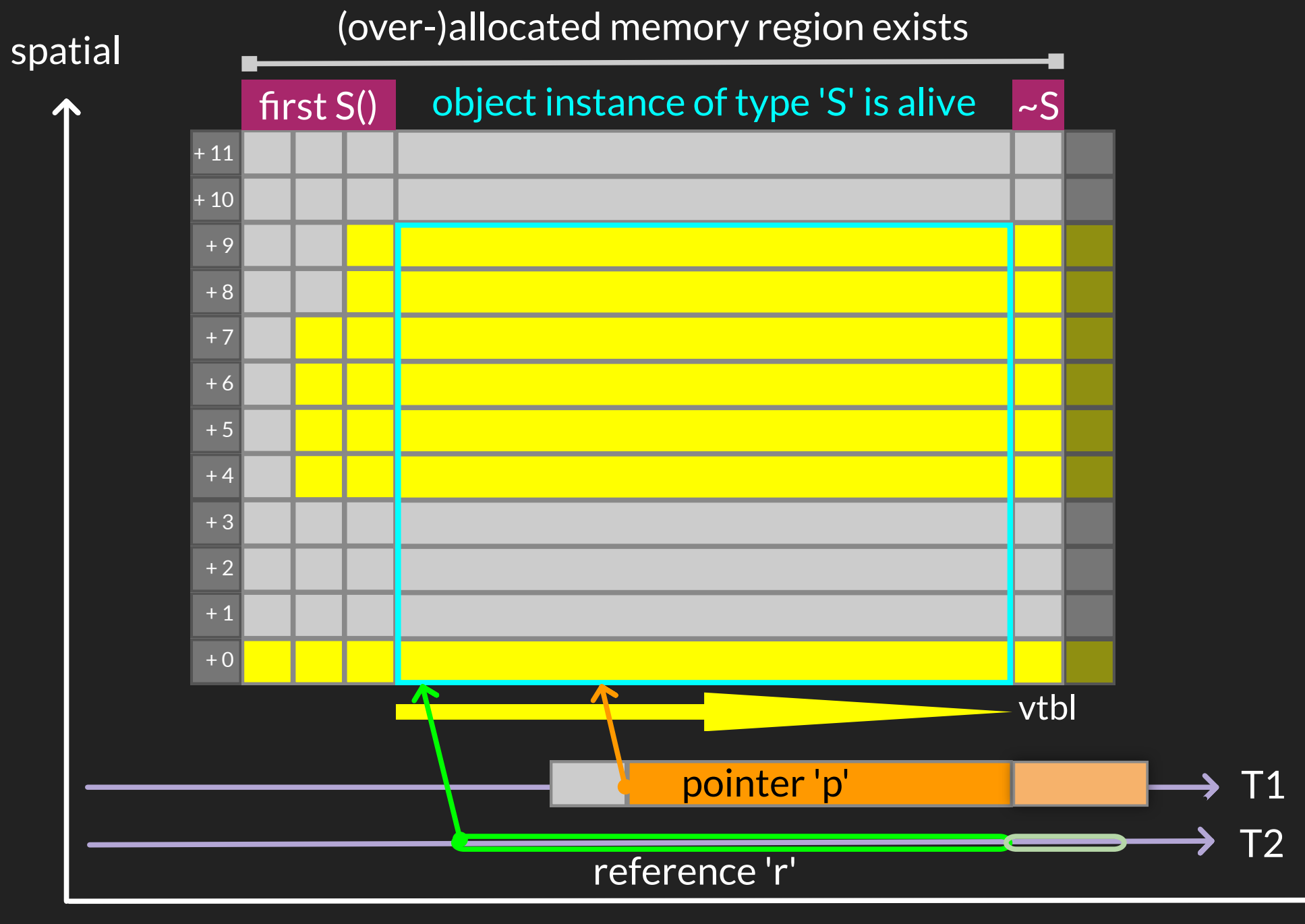


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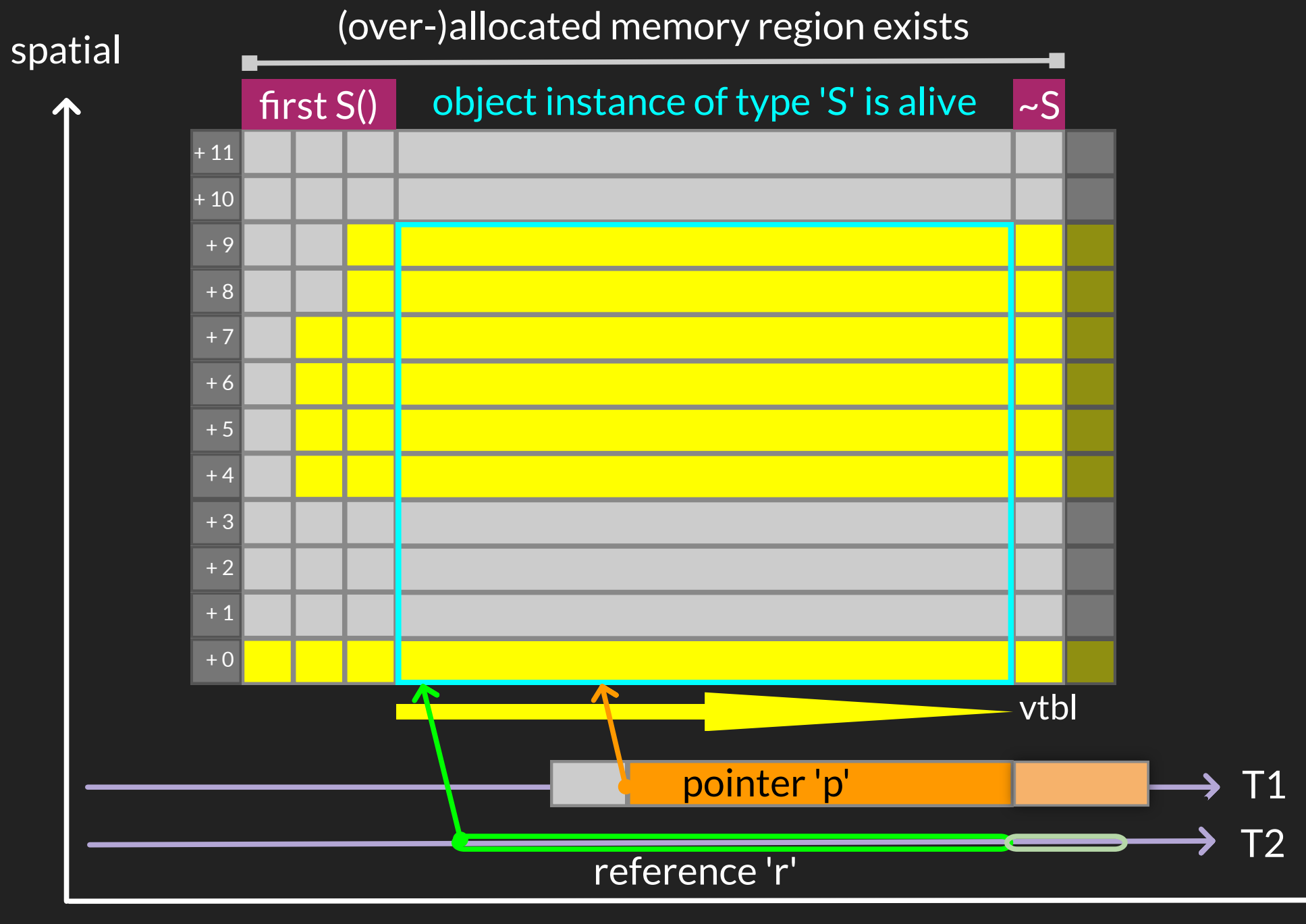


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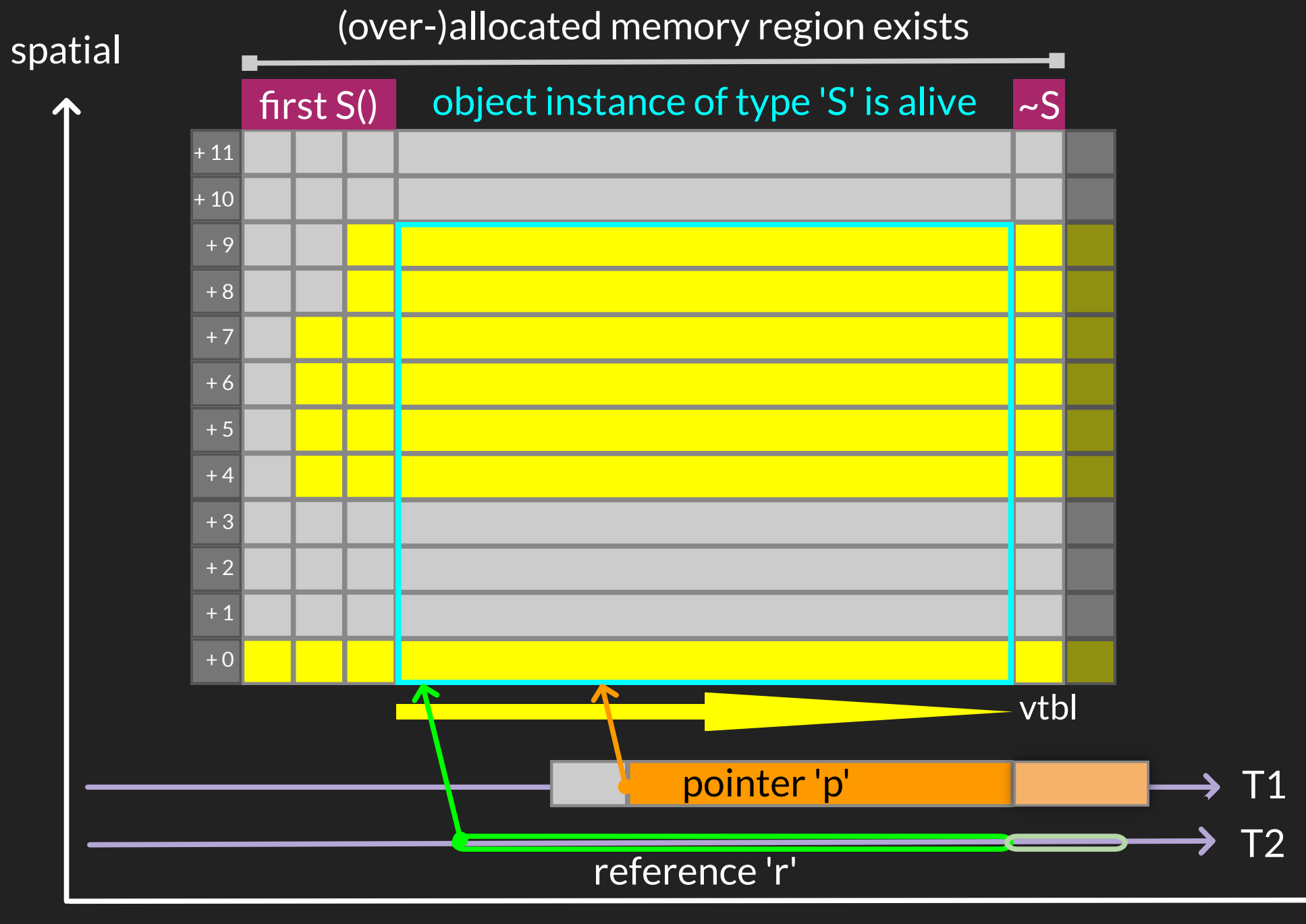


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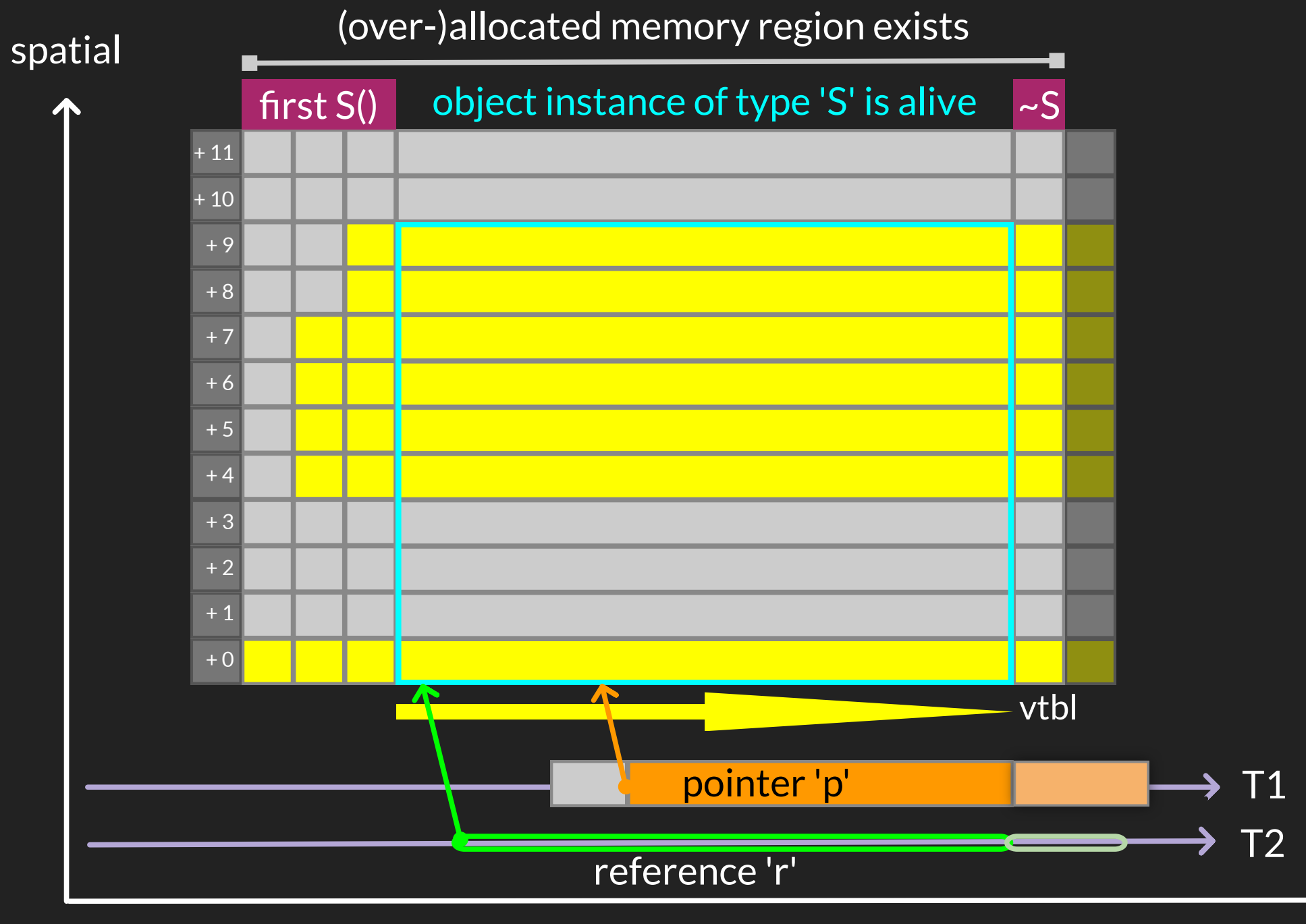


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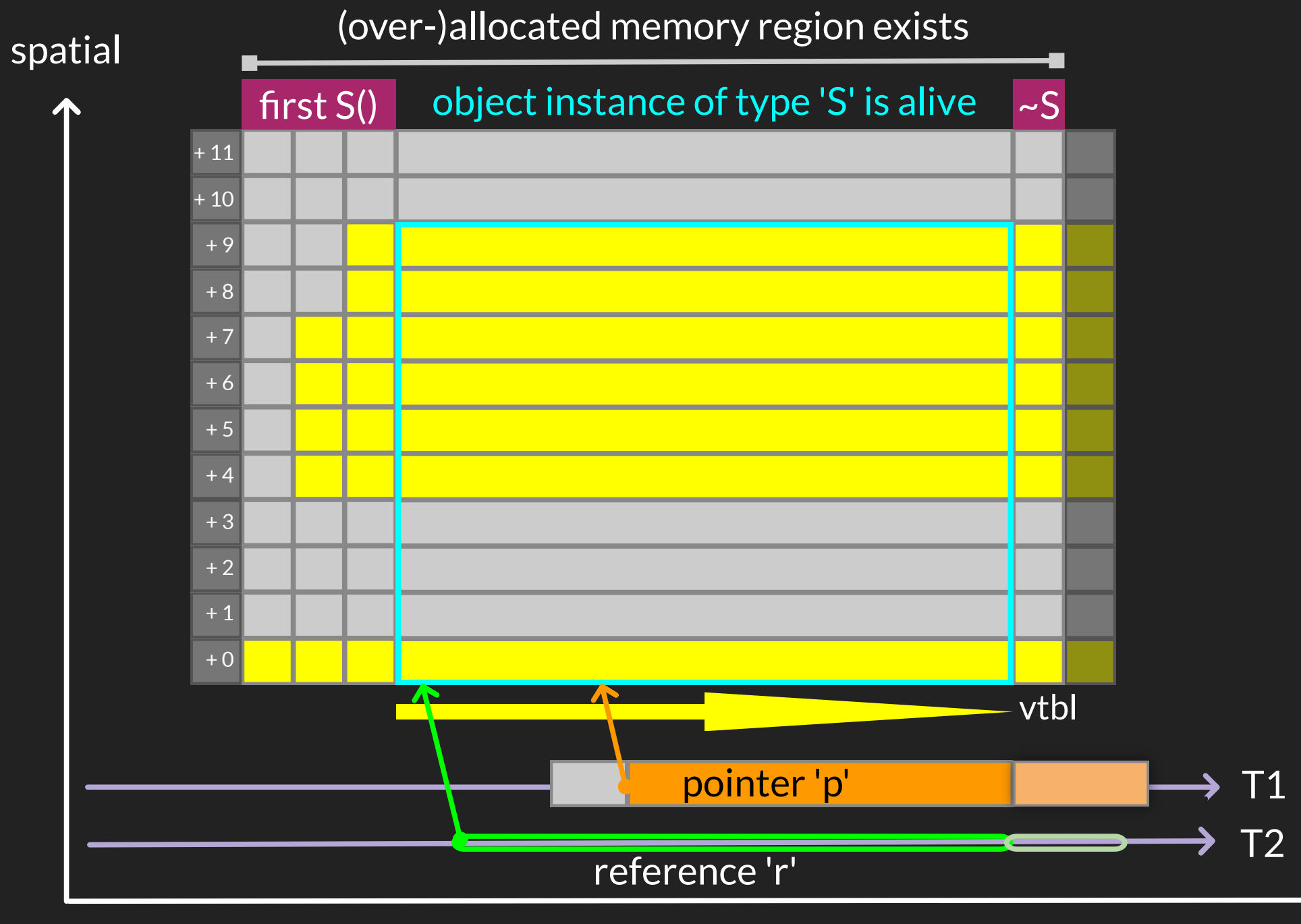


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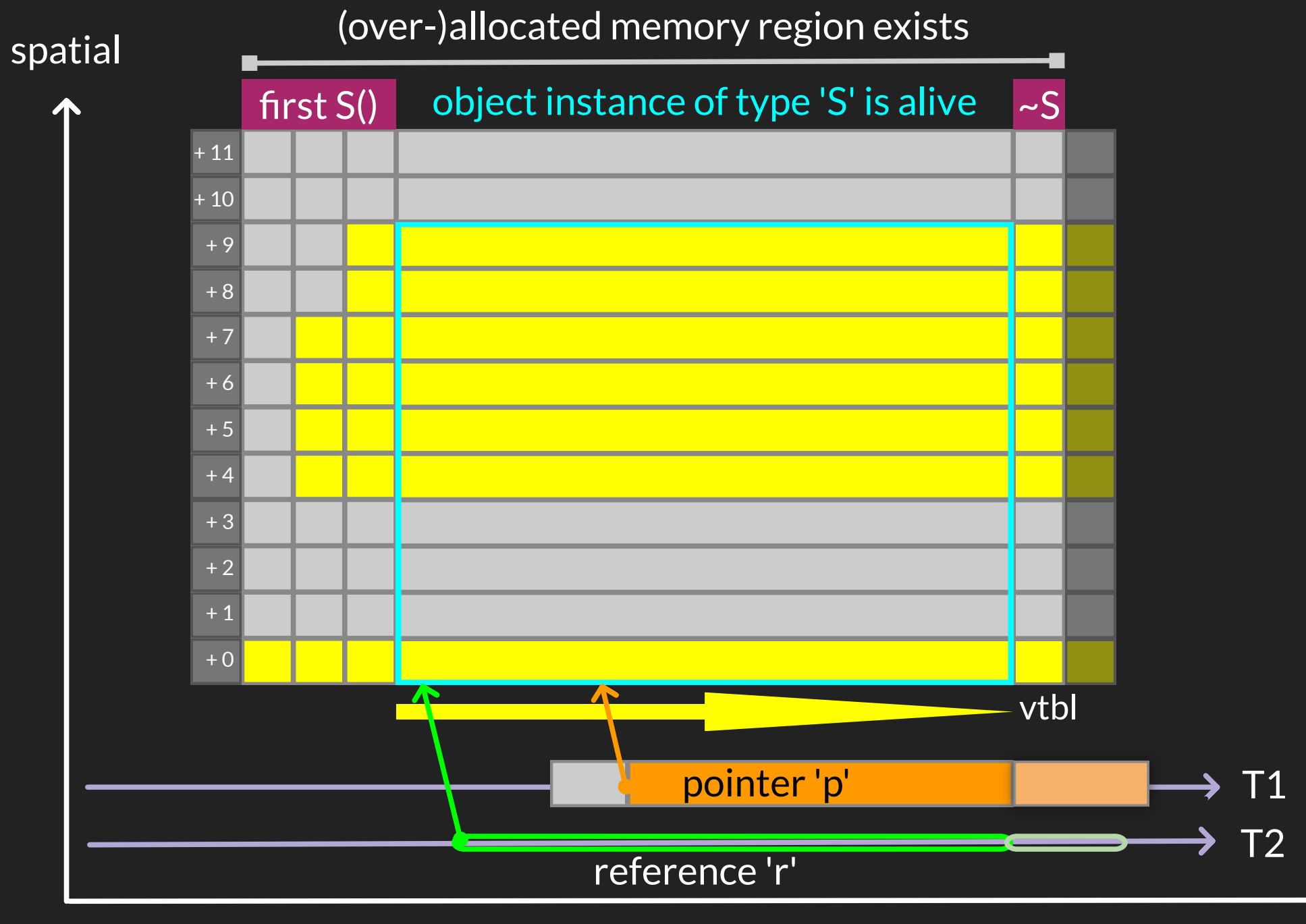


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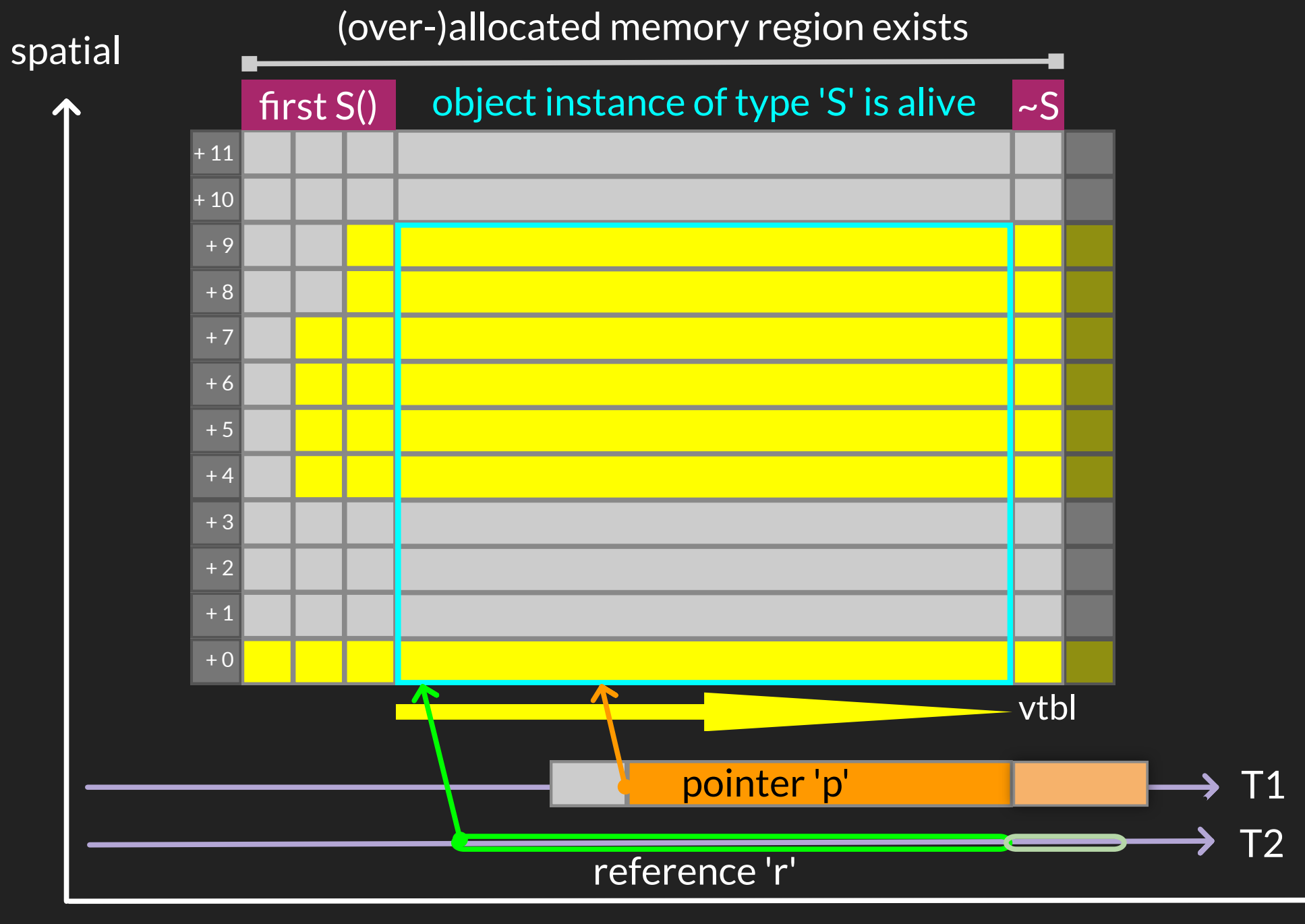


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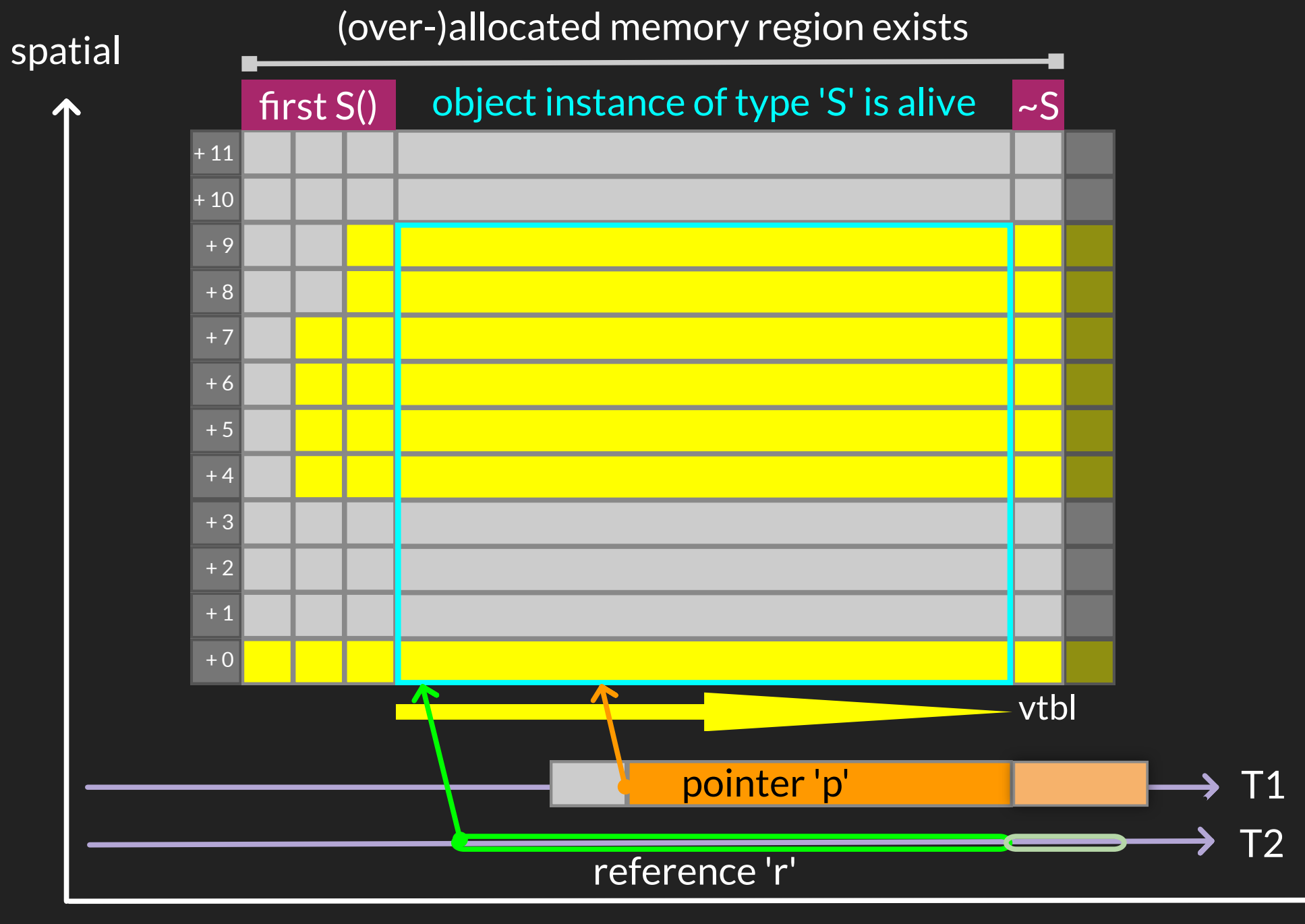


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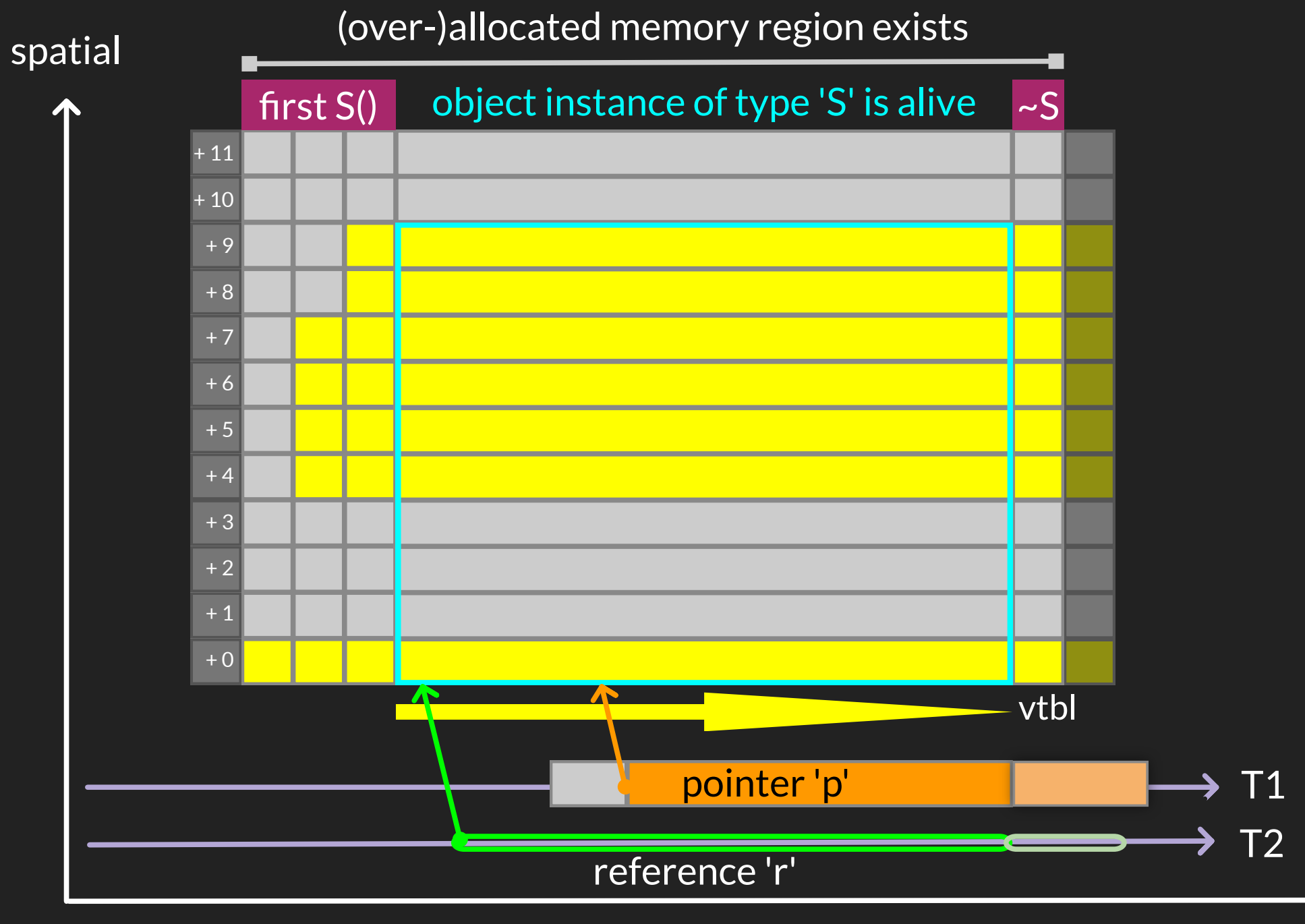


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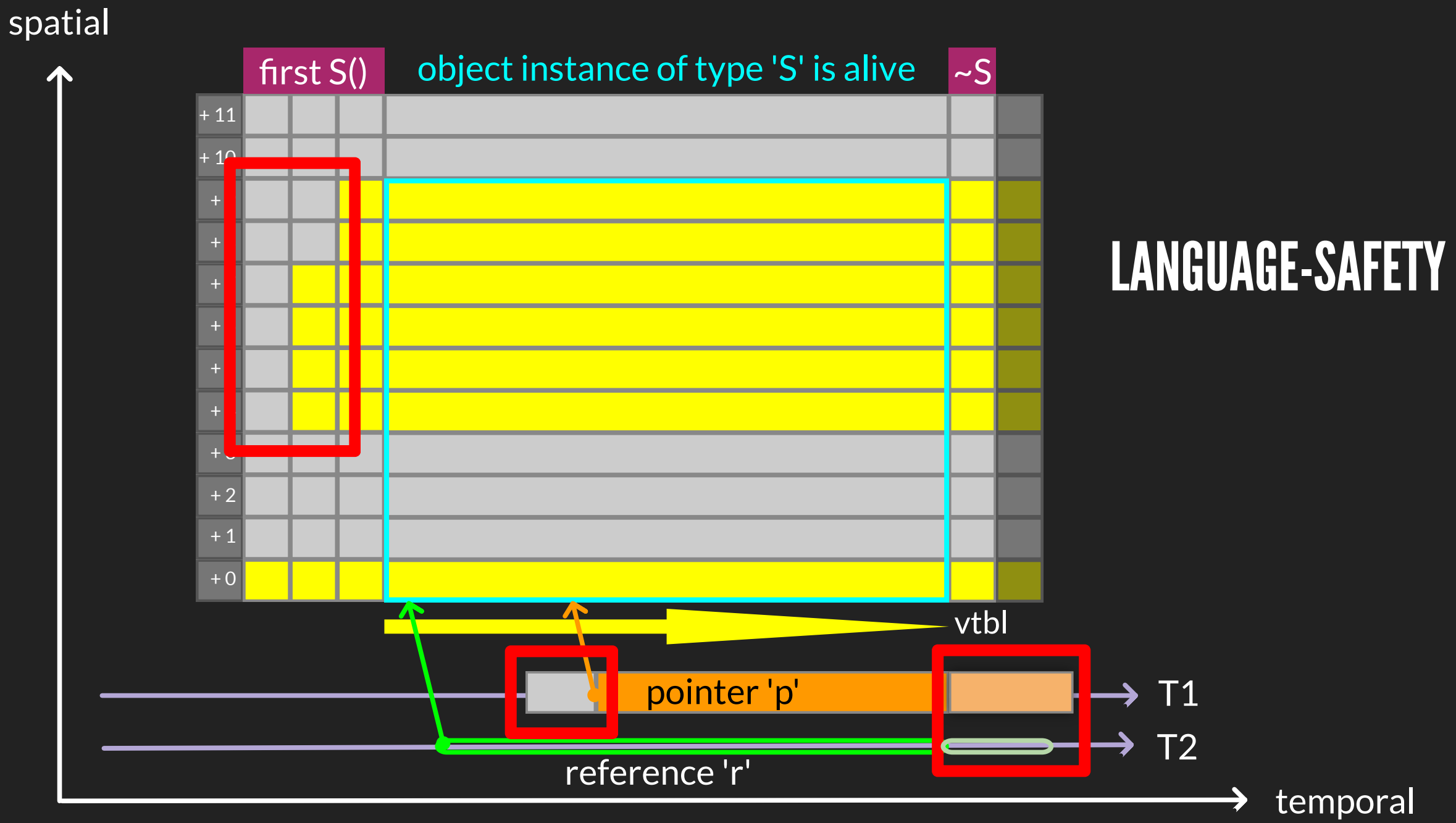
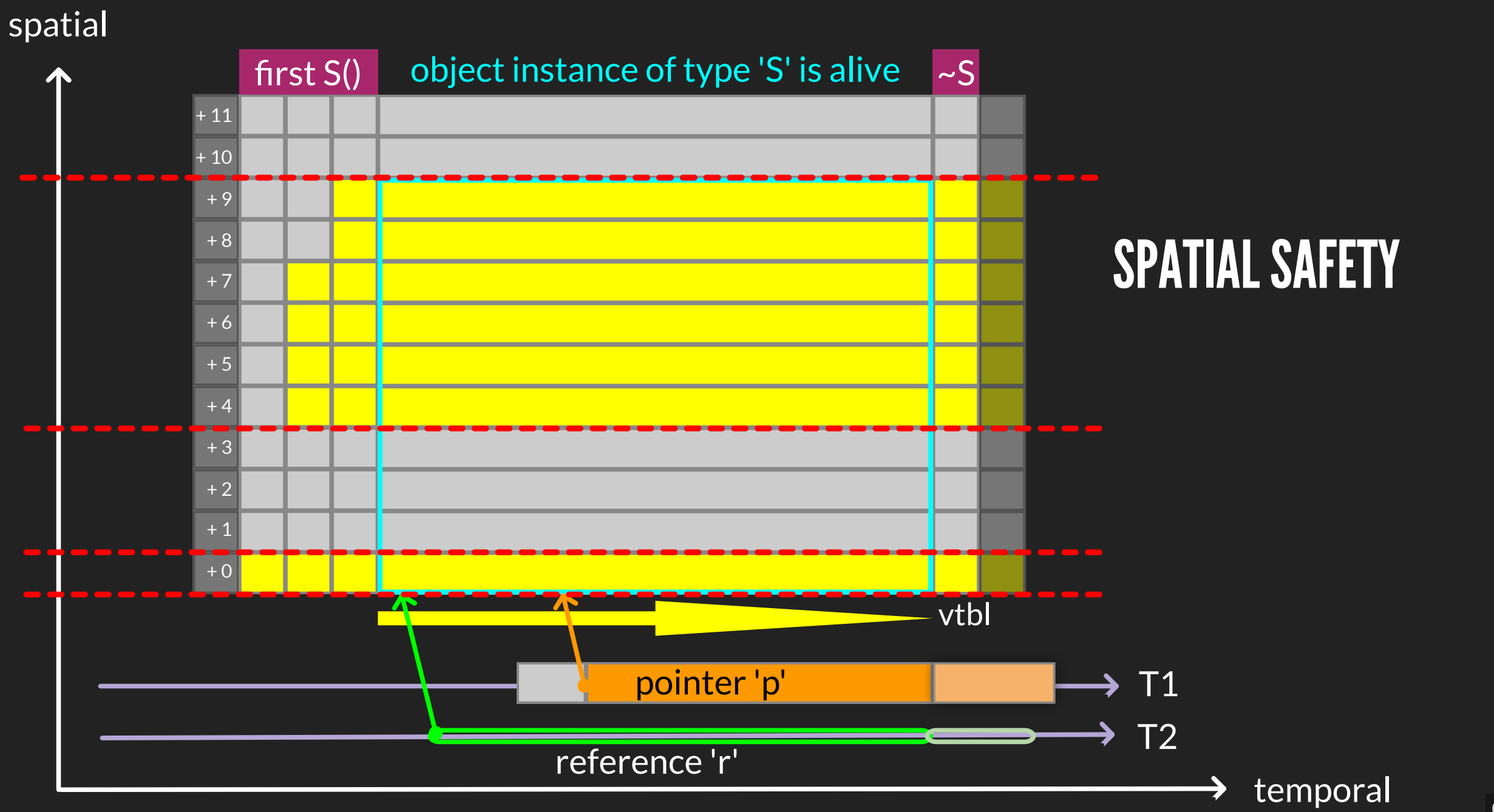
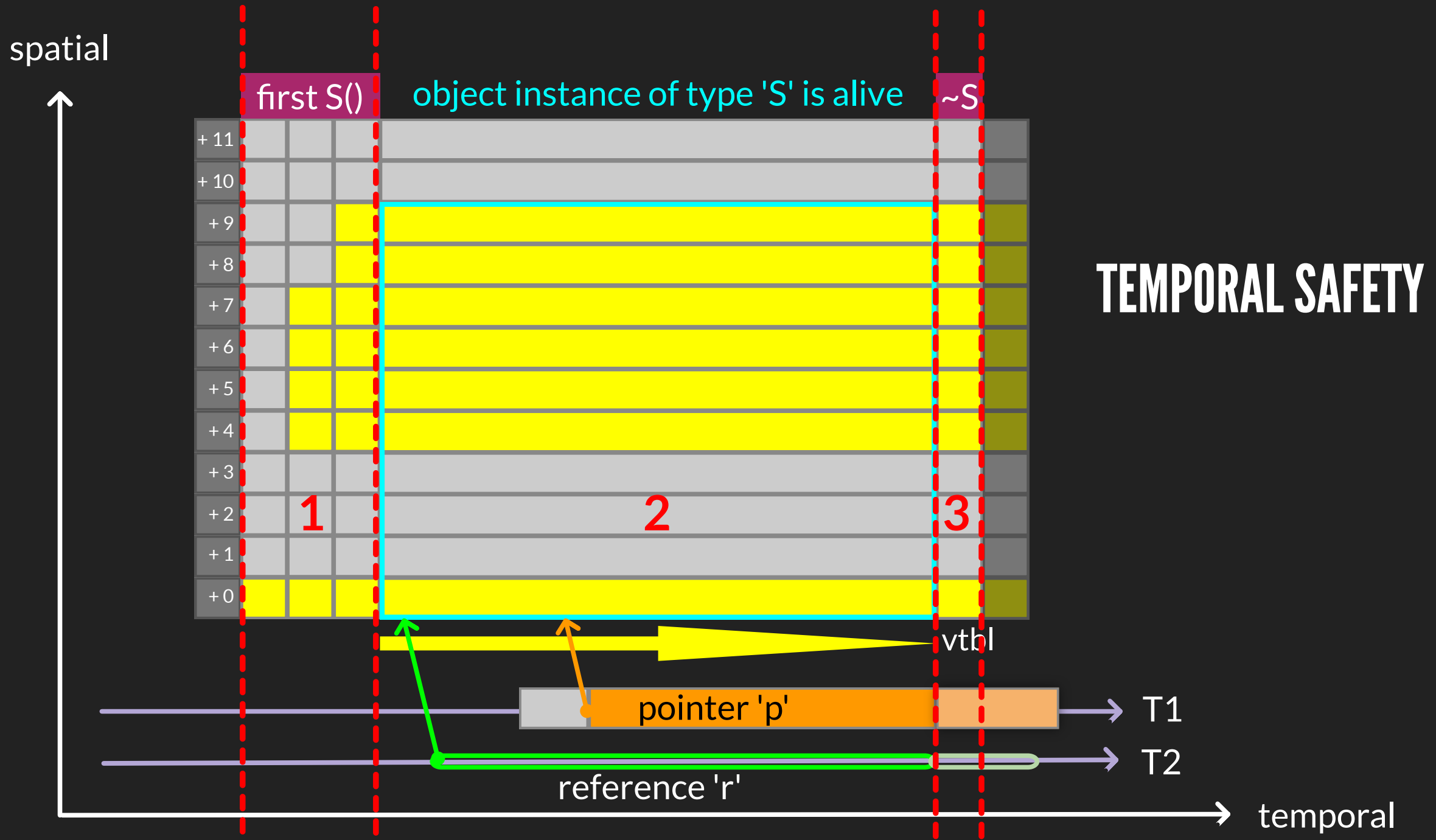
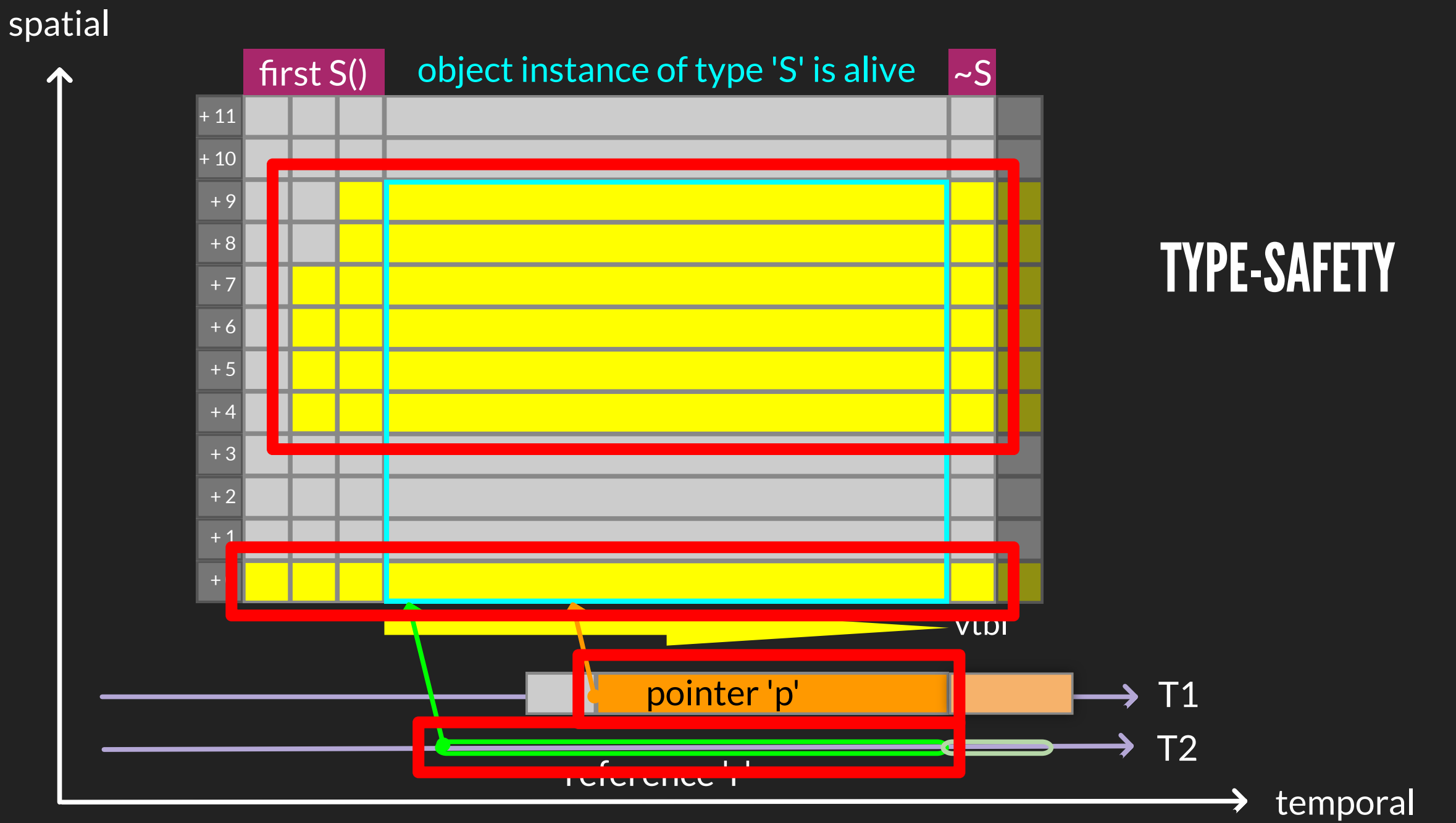


LANGUAGE-SAFETY


spatial
first S()
object instance of type 'S' is alive
~S
+ 11
+ 10
+ 9
+ 8
+ 7
+ 6
+ 5
+ 4
+ 3
+ 2
+ 1
+ 0
SPATIAL SAFETY
vtbl
pointer 'p'
T1
T2
reference 'r'
temporal



TEMPORAL SAFETY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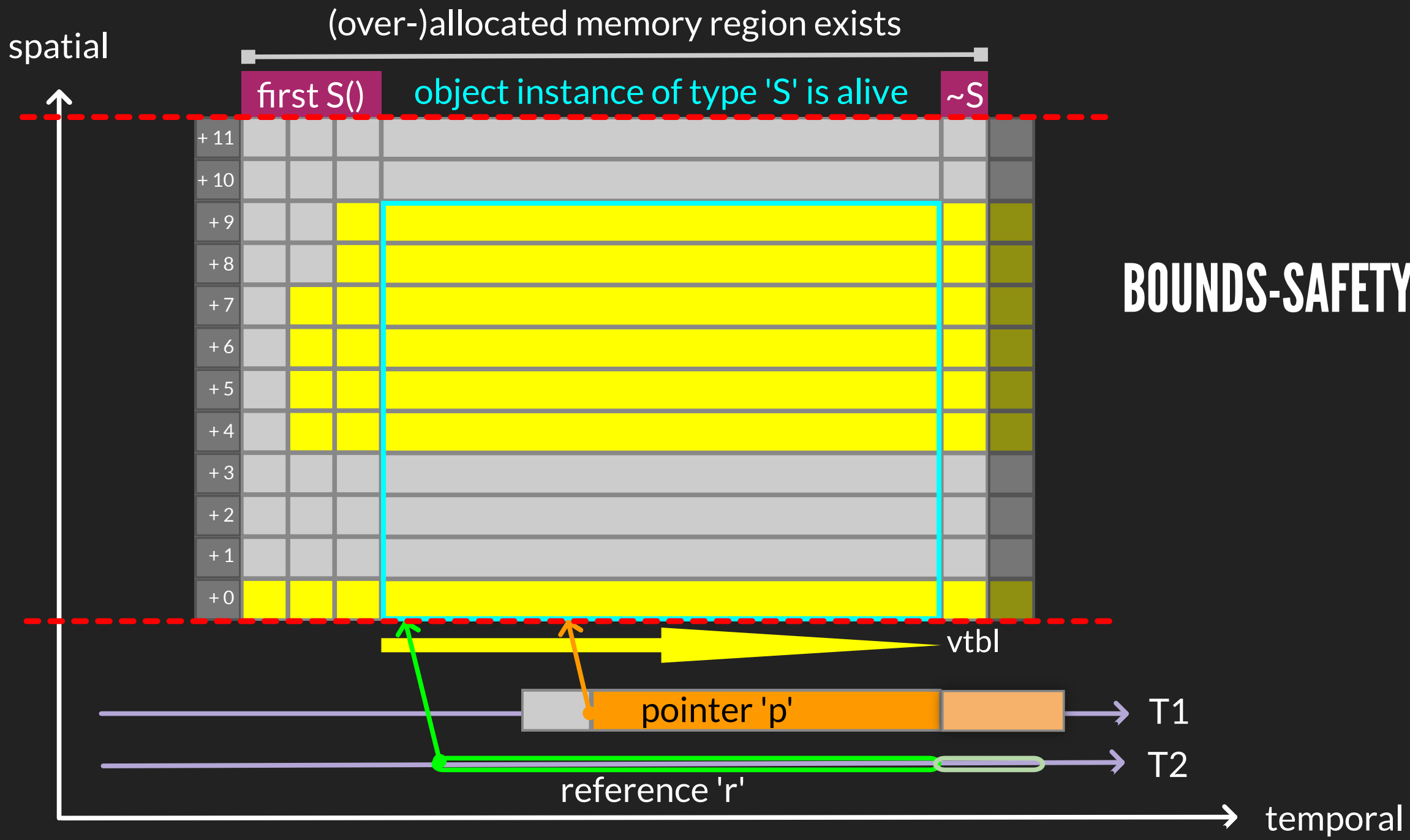
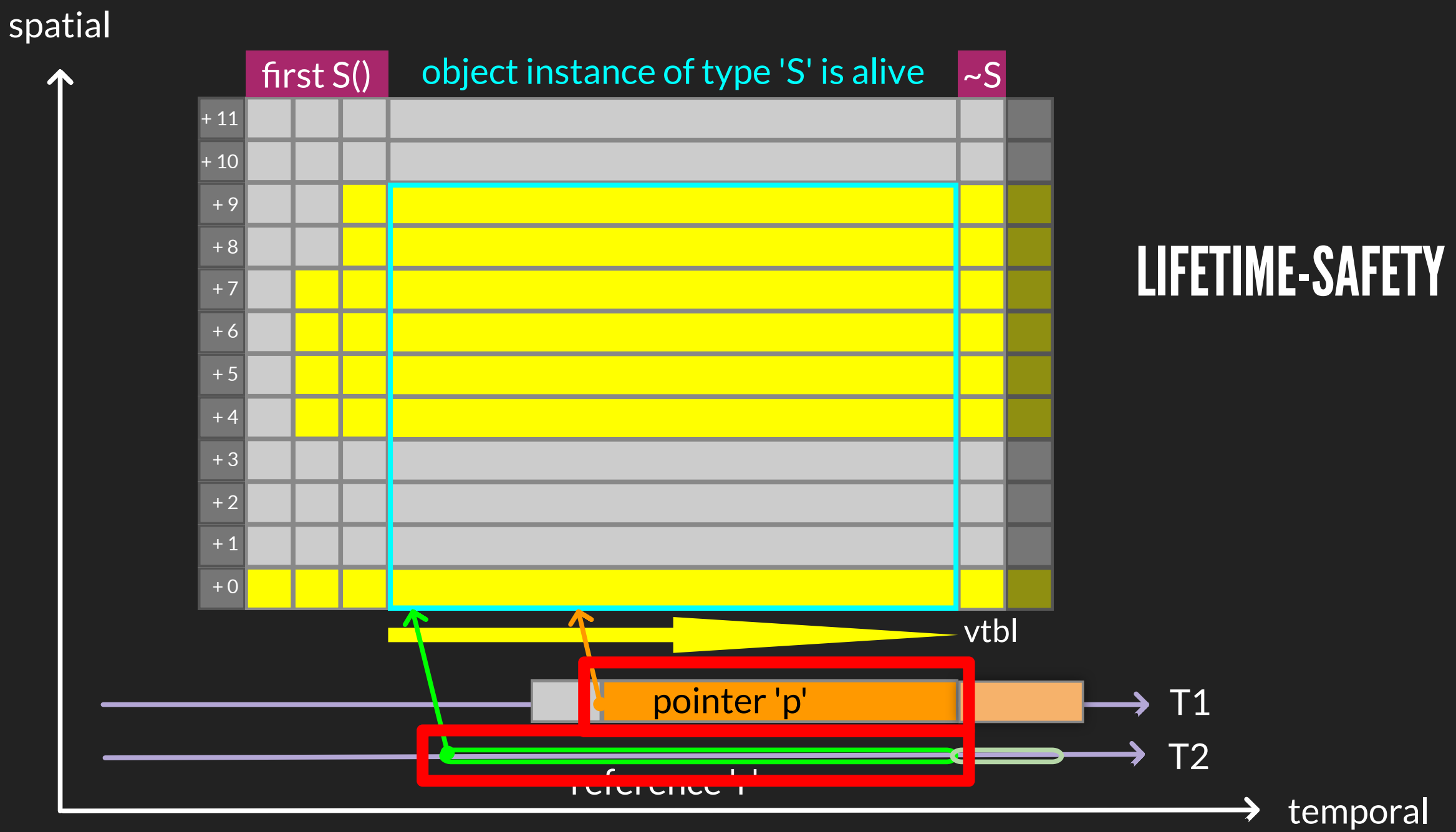
T1
T2
temporal

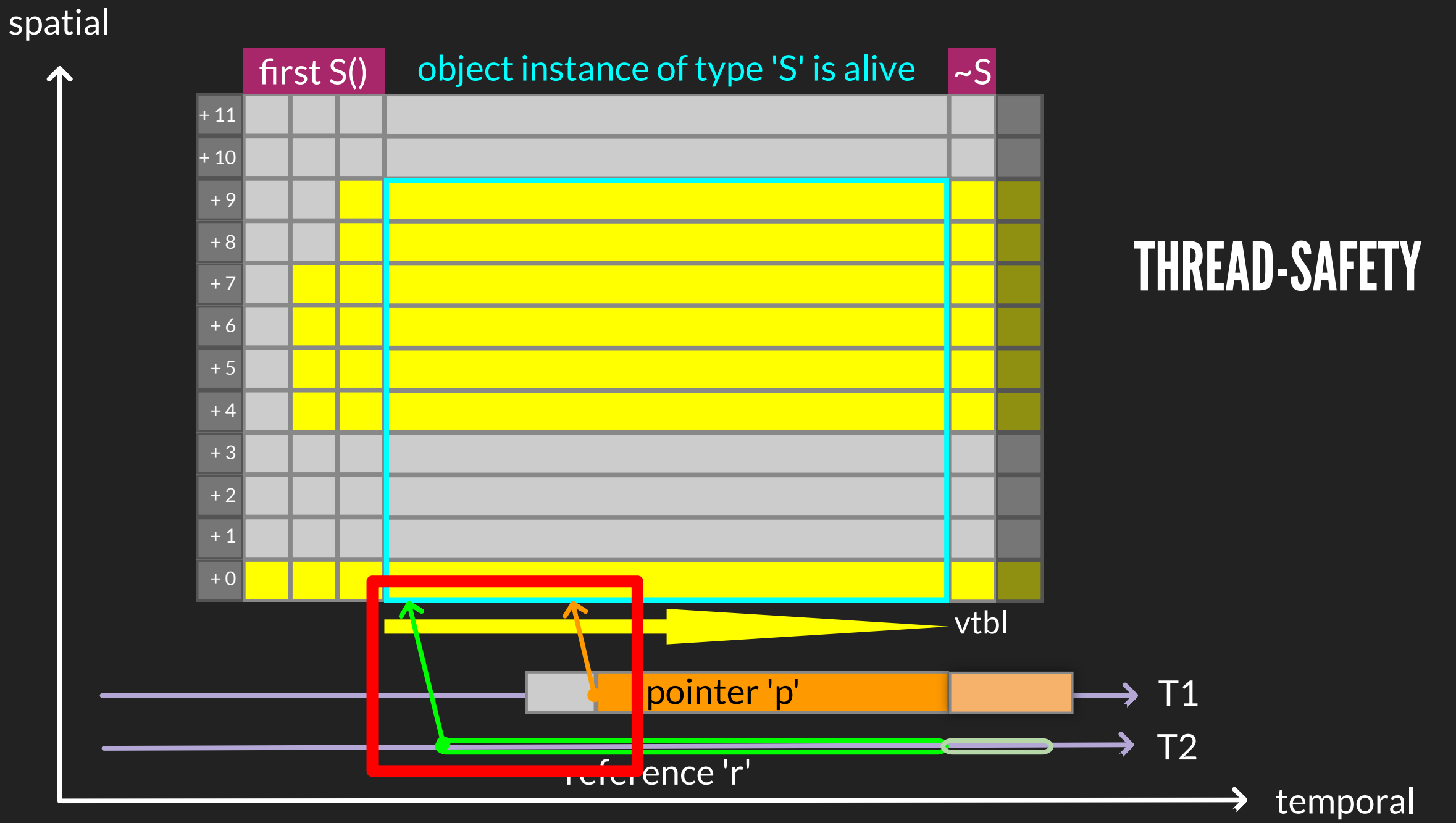
TYPE-SAFETY



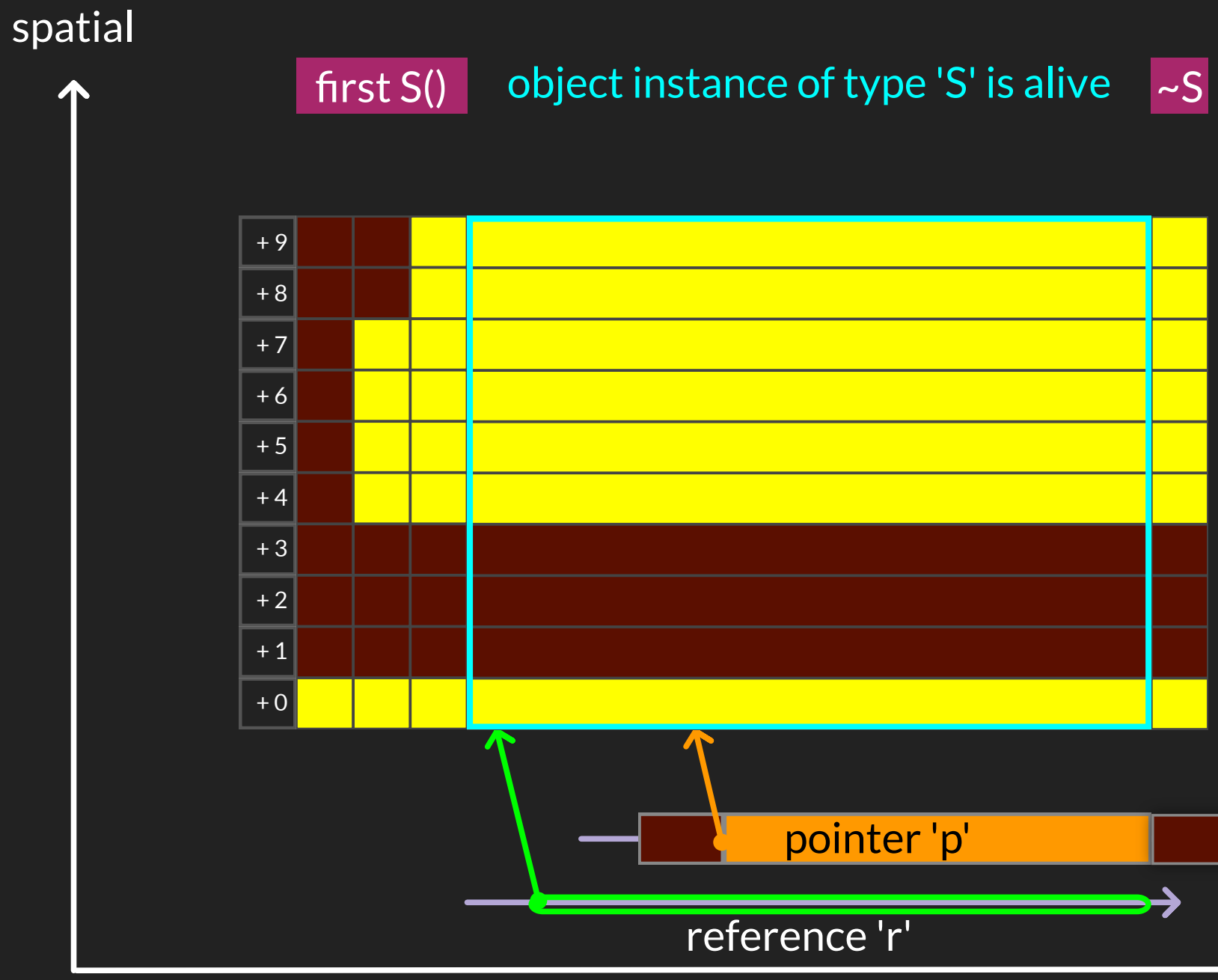
BOUNDS-SAFETY



LIFETIME-SAFETY



THREAD-SAFETY




```
struct S {
  S();
  virtual ~S();

  char    a = 1;
  int32_t b = 2;
  int16_t c = 3;
};

constexpr
void Function1 {
  S _;
  S * p = &_;
}

constexpr
void Function2 {
  S _;
  S & r = _;
}
```