SanRazor: Reducing Redundant Sanitizer Checks in C/C++ Programs

Jiang Zhang[1], Shuai Wang[2], Manuel Rigger[3], Pinjia He[3], Zhendong Su[3]

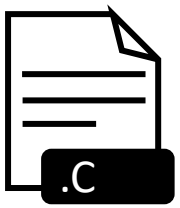
1: *University of Southern California*

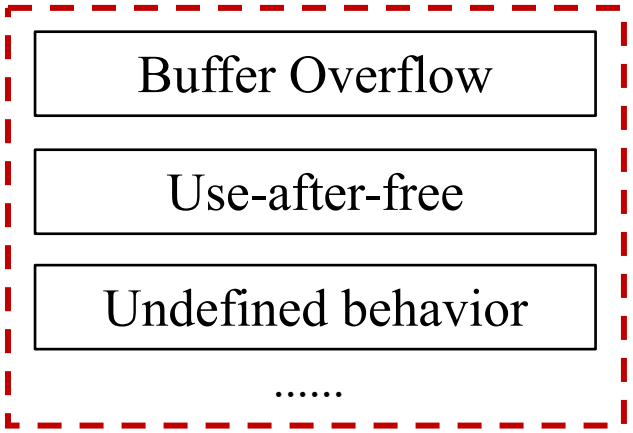
2: *HKUST*

3: *ETH Zurich*

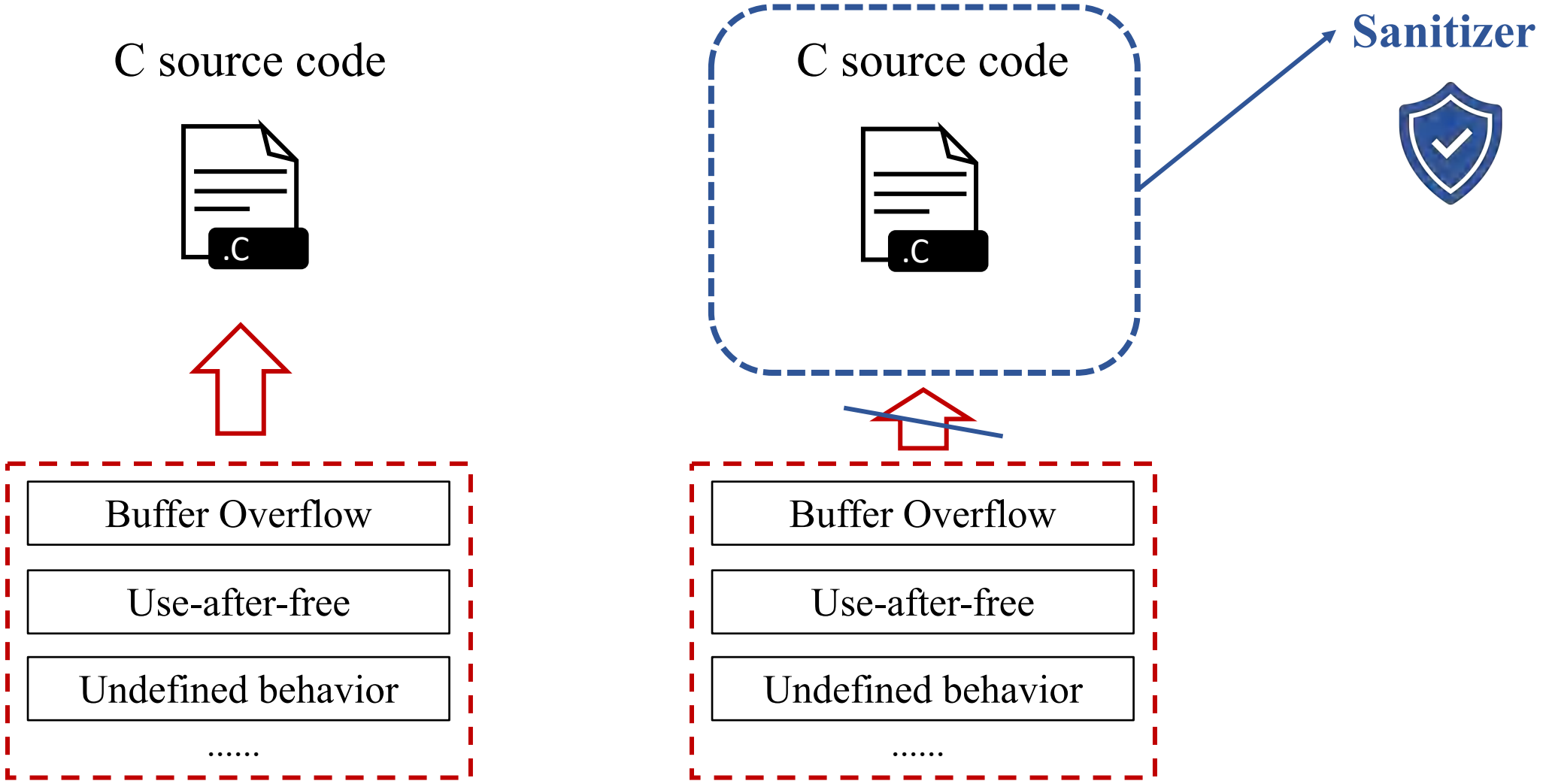
C/C++ programs are unsafe

C source code

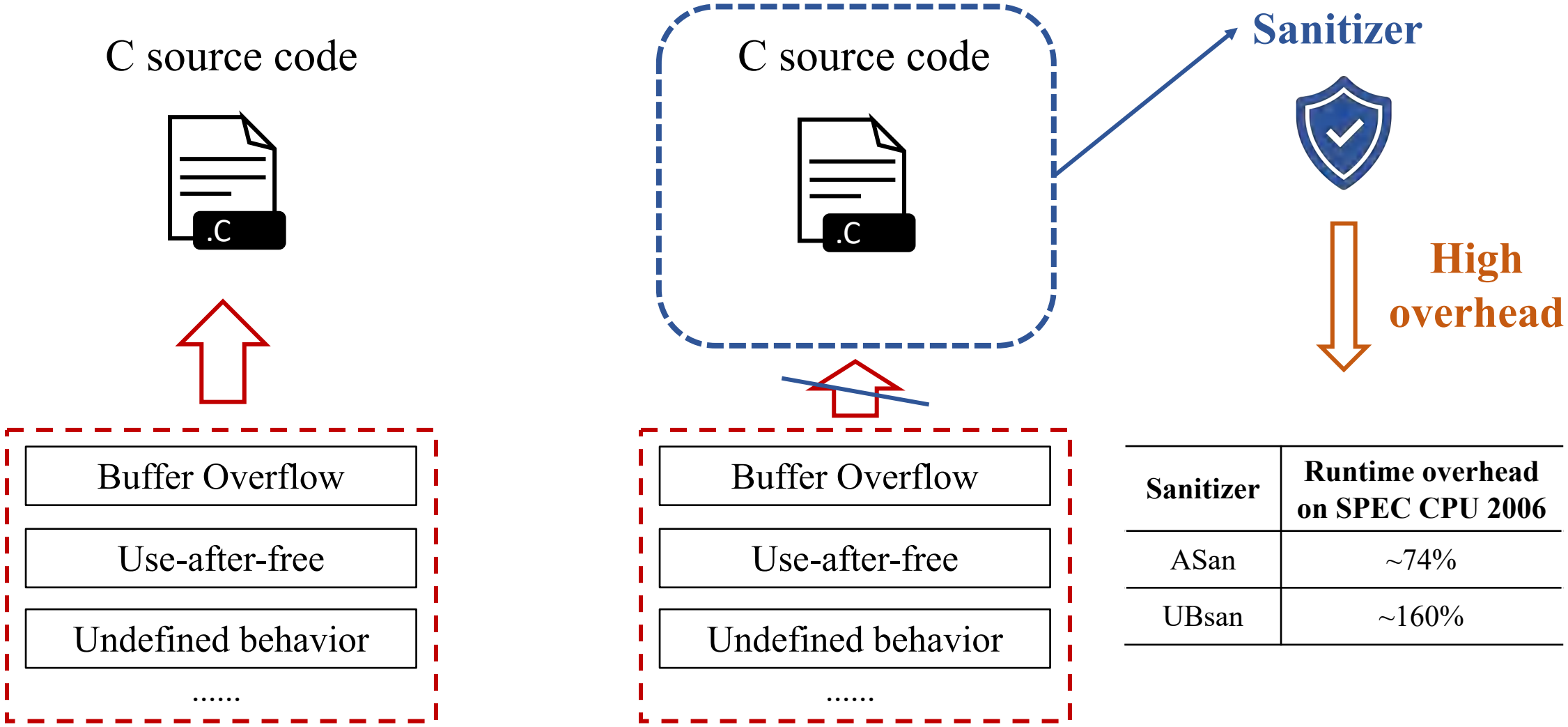




Sanitizers are designed to detect software bugs/vulnerabilities

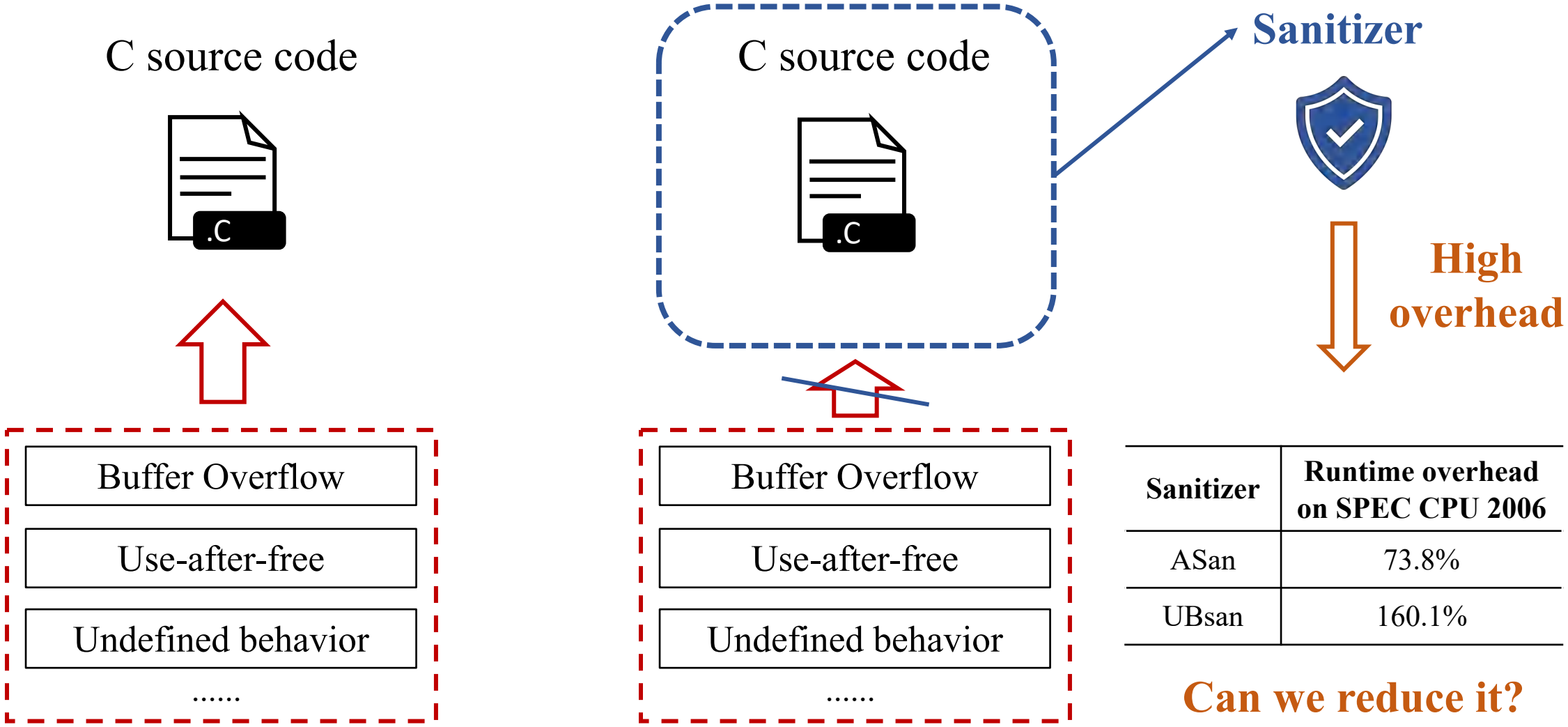


However, sanitizers have high runtime overhead



Sanitizer	Runtime overhead on SPEC CPU 2006
ASan	~74%
UBsan	~160%

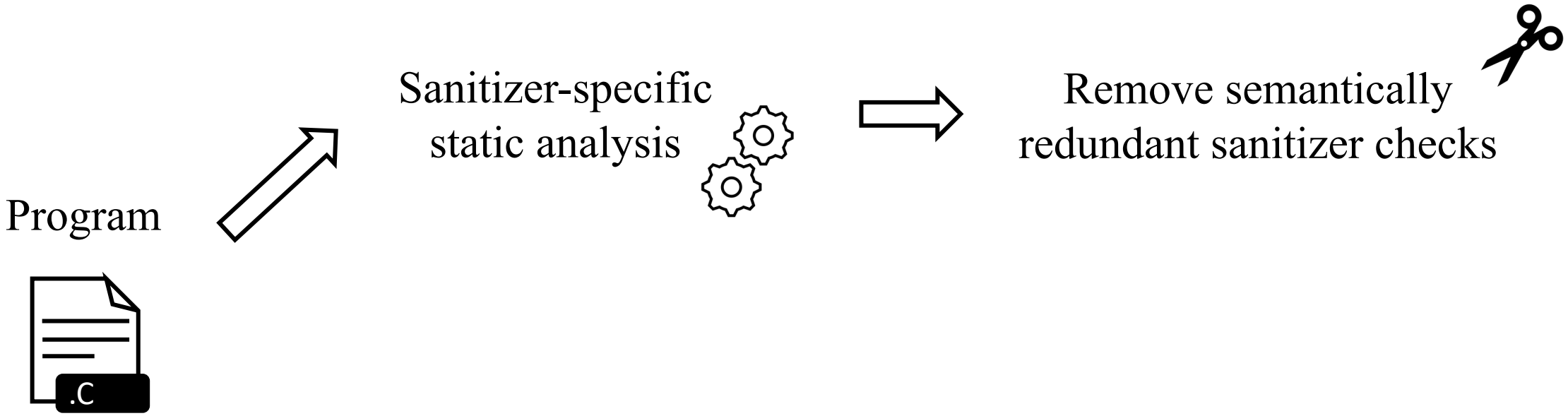
However, sanitizers have high runtime overhead



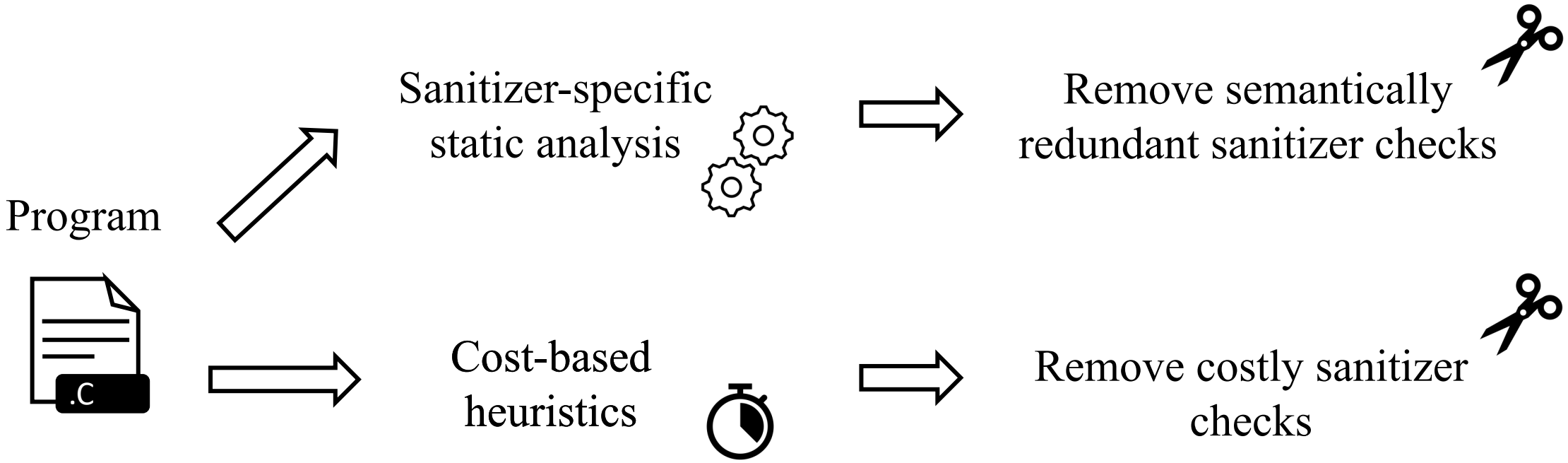
Sanitizer	Runtime overhead on SPEC CPU 2006
ASan	73.8%
UBsan	160.1%

Can we reduce it?

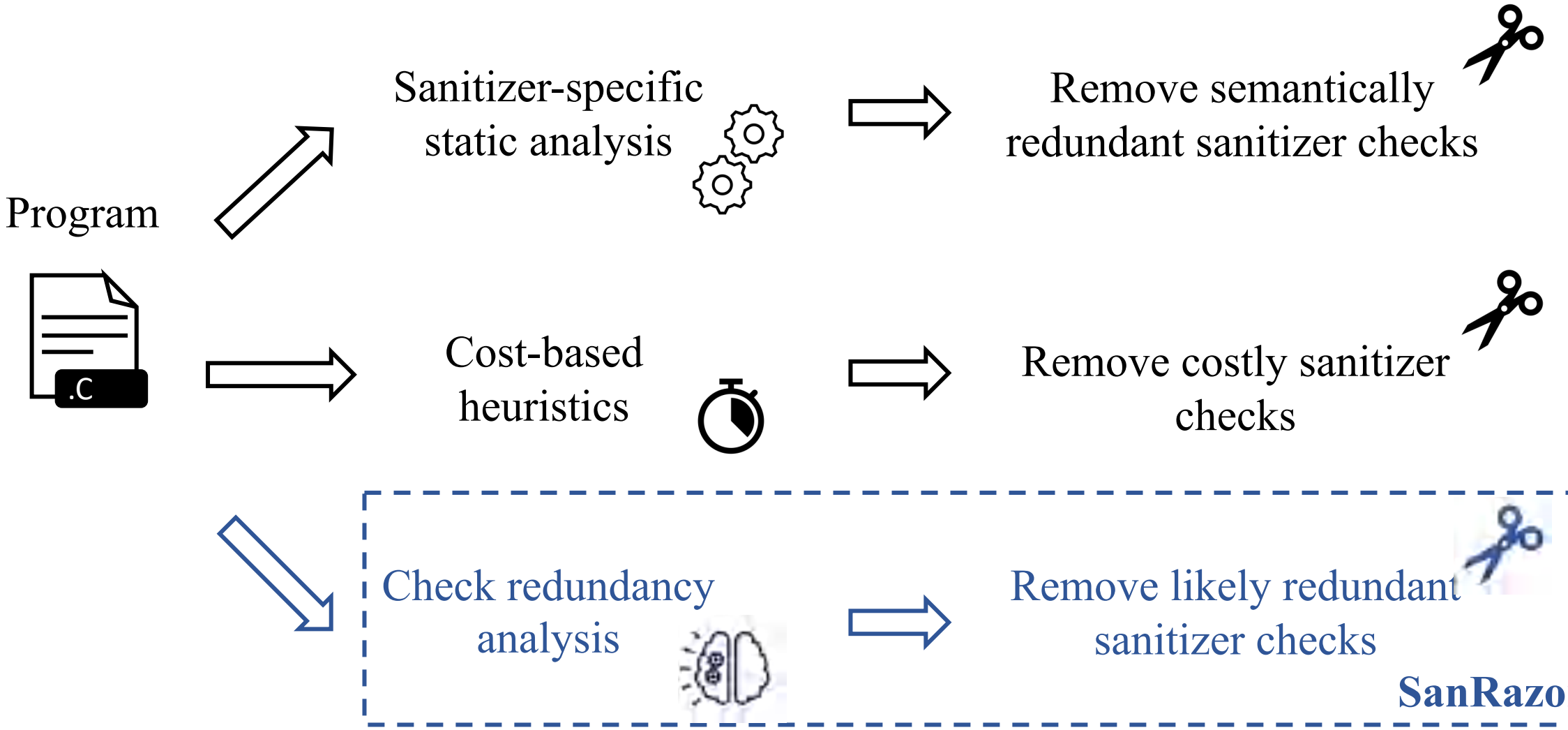
Prior approaches



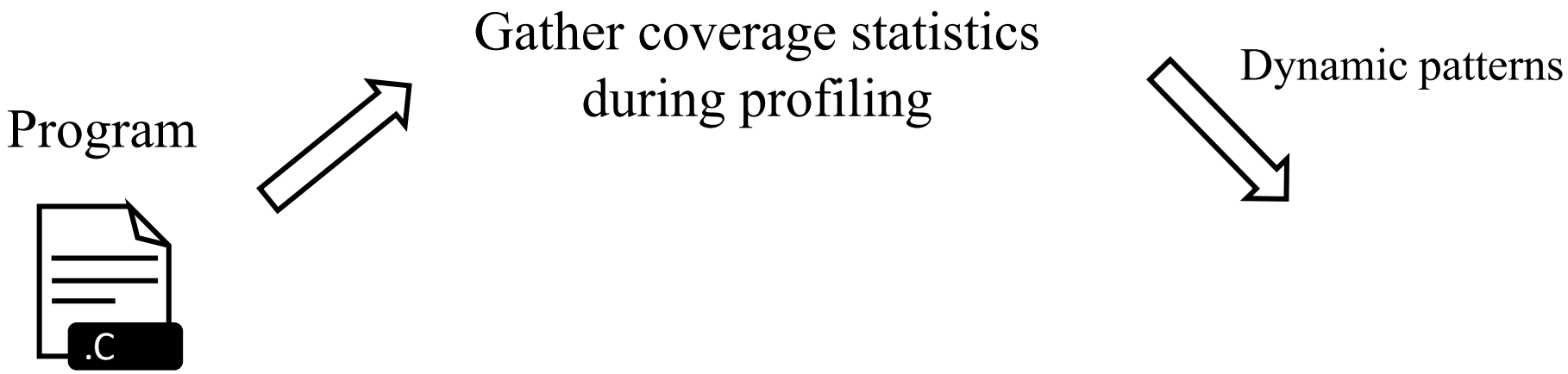
Prior approaches



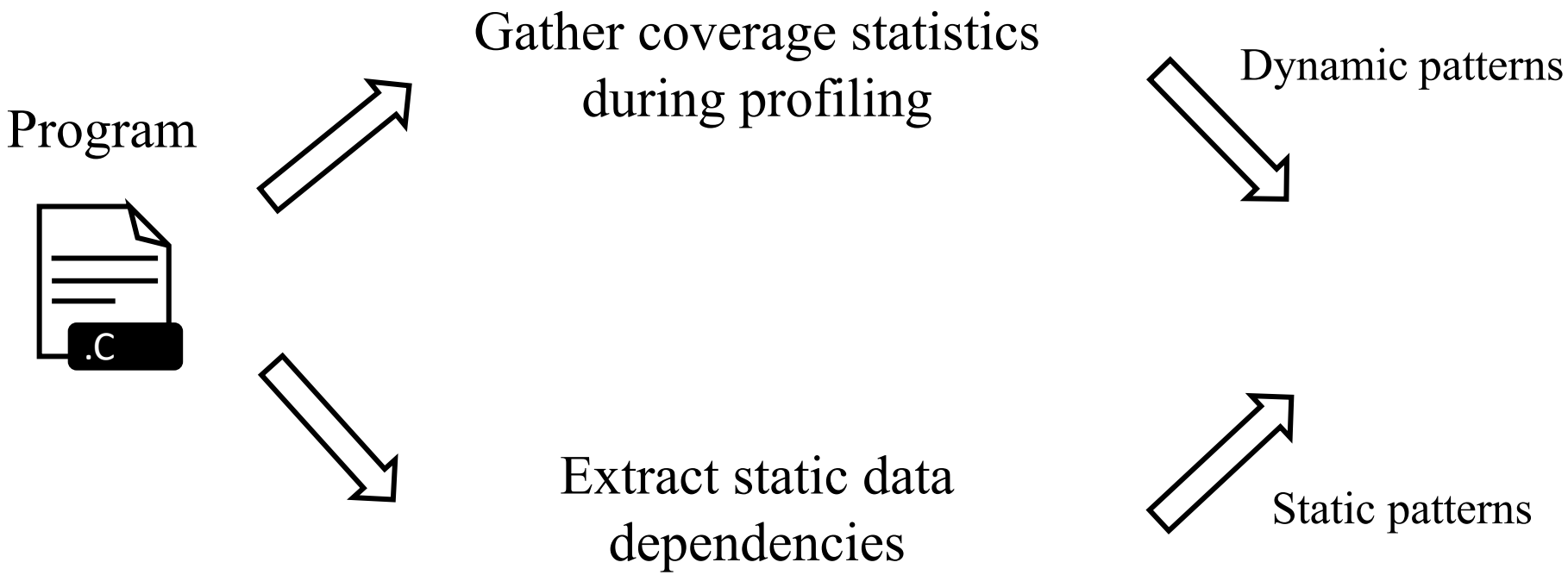
Our novel design



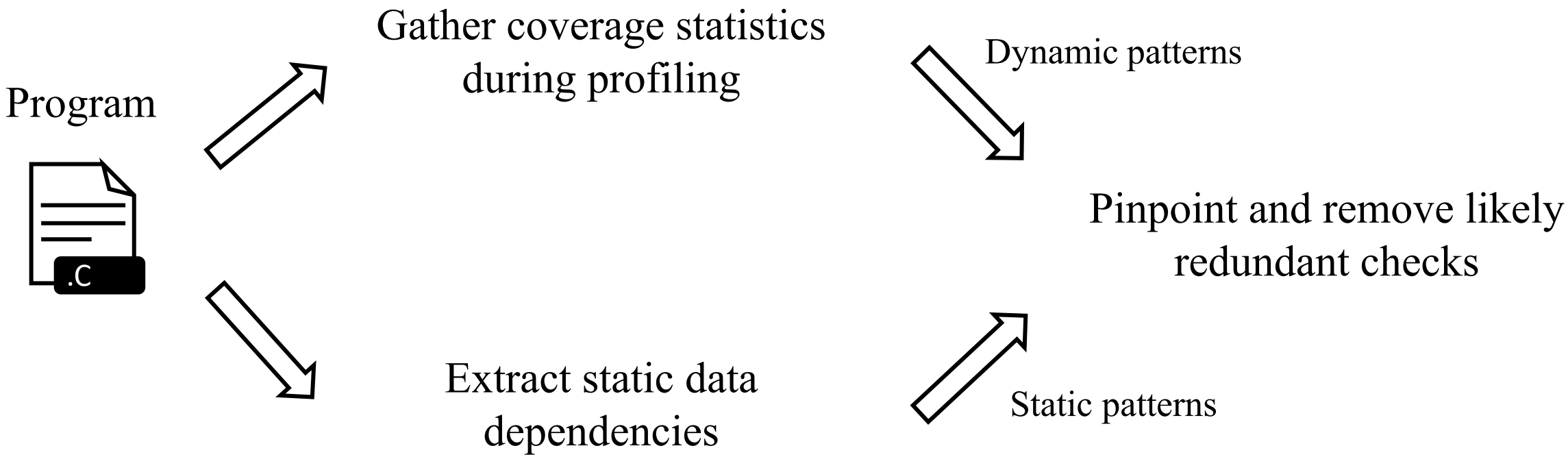
Design: overall workflow



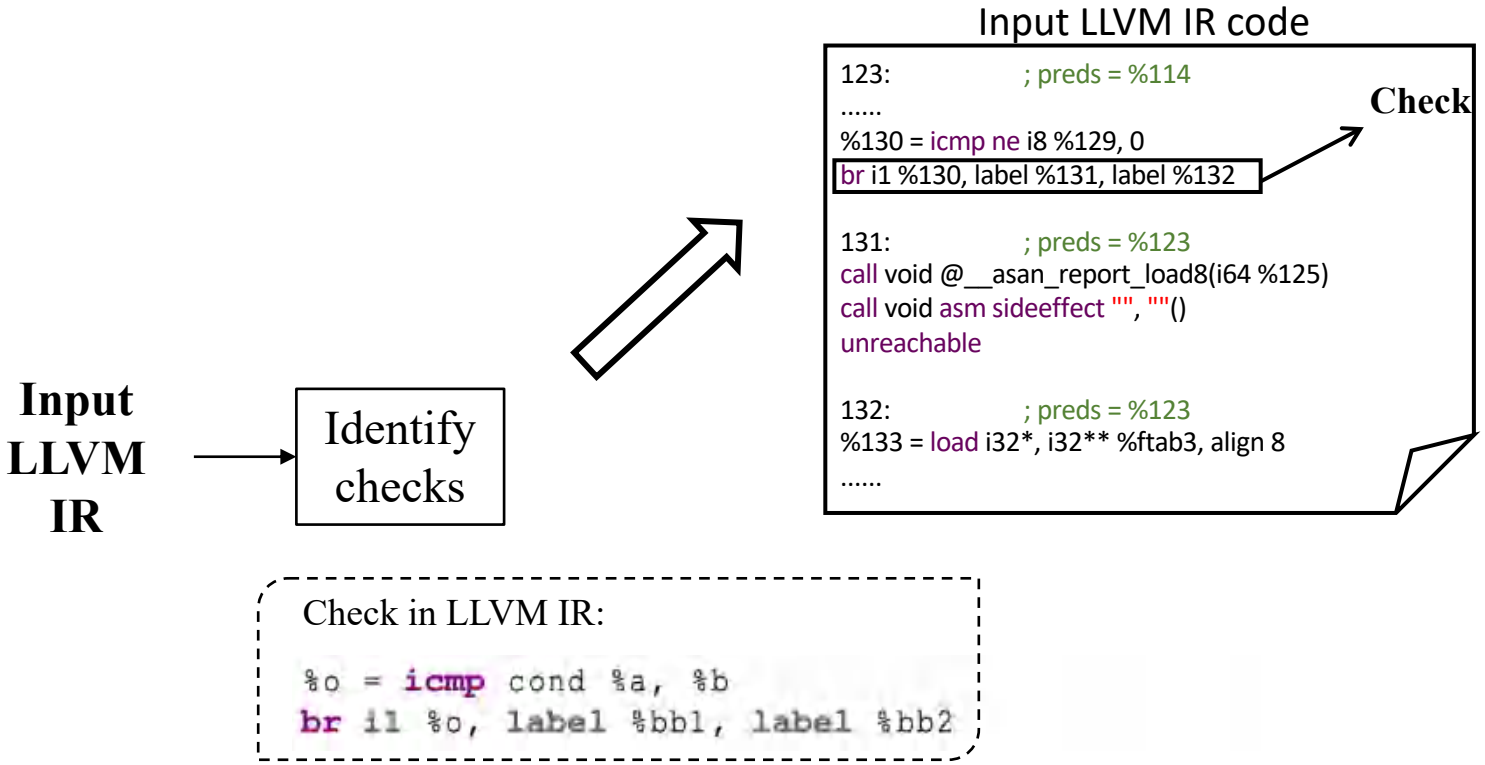
Design: overall workflow



Design: overall workflow



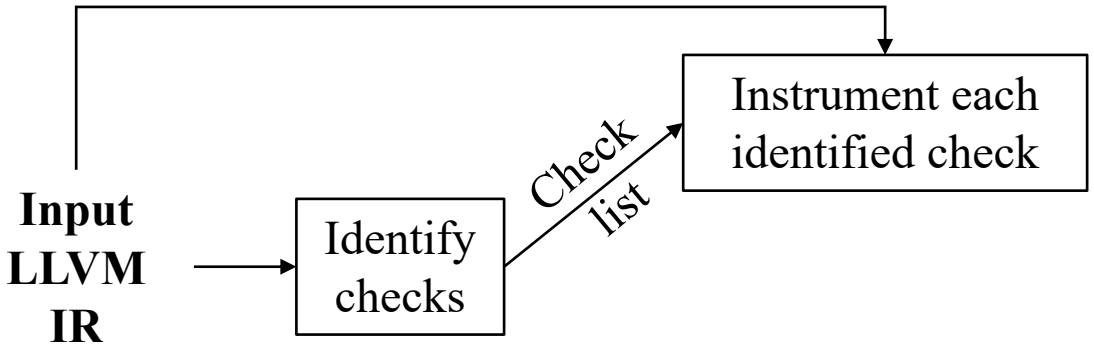
Design: check identification



Check in LLVM IR:

```
%o = icmp cond %a, %b
br i1 %o, label %bb1, label %bb2
```

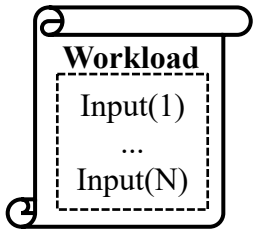
Design: check identification

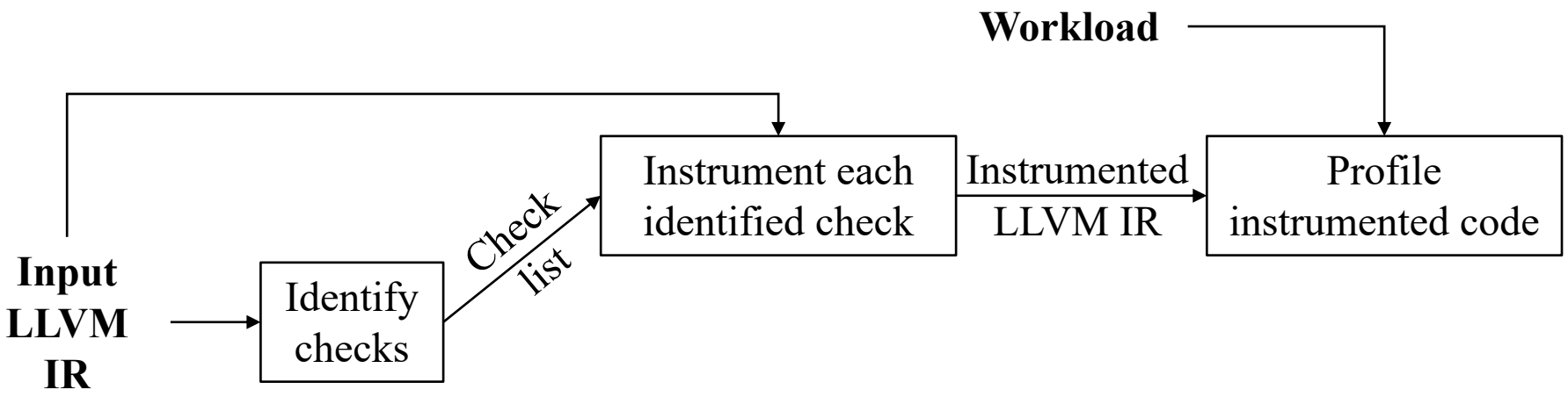


Instrumented LLVM IR code

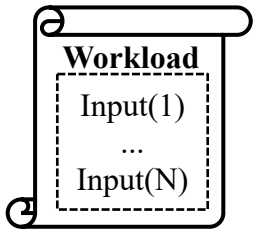
```
123:                ; preds = %114
......
%130 = icmp ne i8 %129, 0
call void @COUNTER_calledSCbzip2(i64 32, i1 %130)
br i1 %130, label %131, label %132

131:                ; preds = %123
call void @__asan_report_load8(i64 %125)
call void asm sideeffect "", ""()
unreachable

132:                ; preds = %123
%133 = load i32*, i32** %ftab3, align 8
......
```

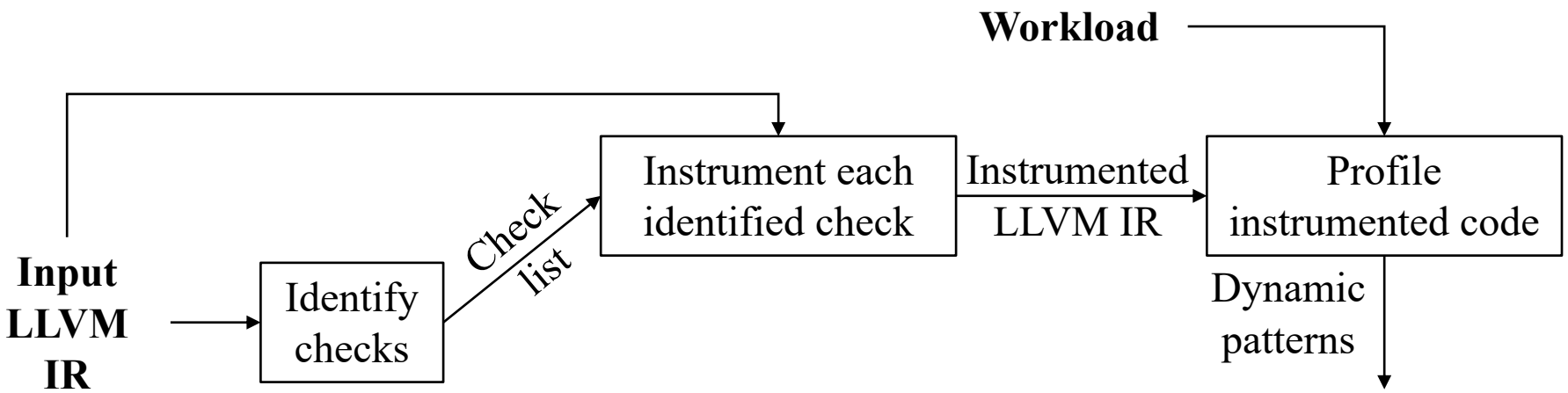
Design: dynamic pattern capturing





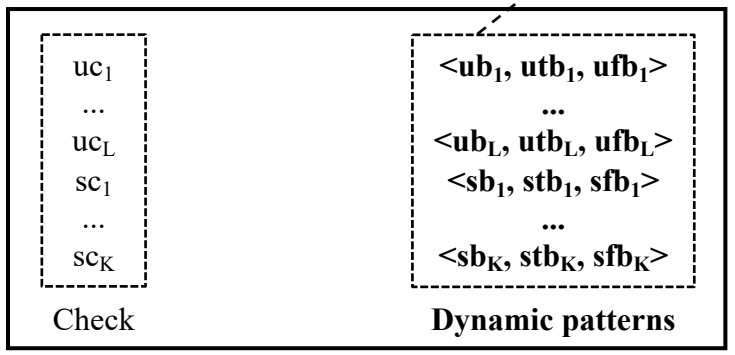
Design: dynamic pattern capturing



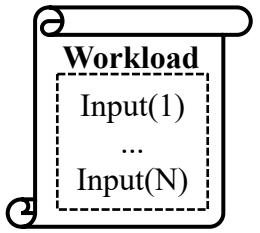


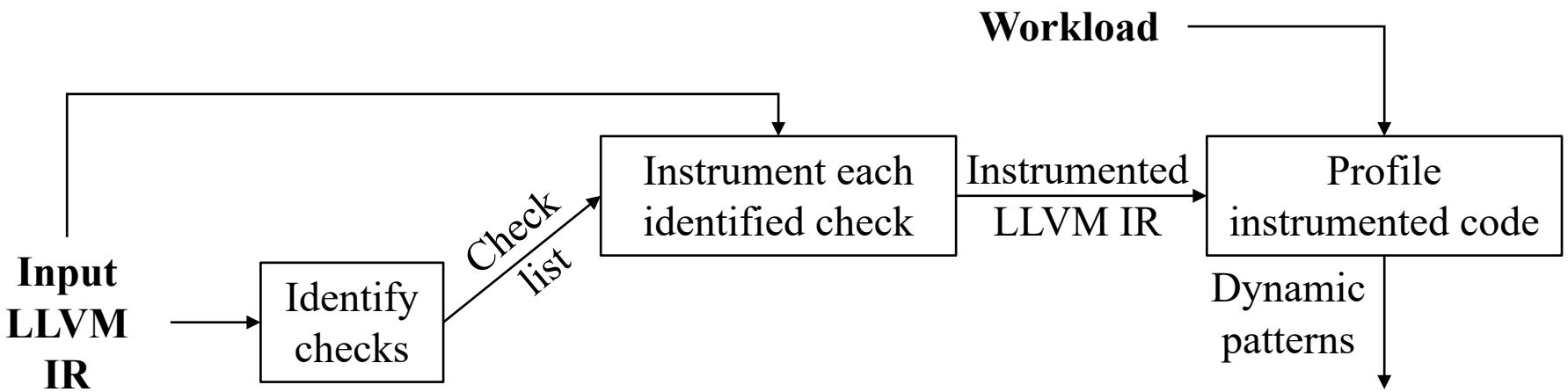

```
%o = icmp cond %a, %b
br i1 %o, label %bb1, label %bb2
```

Total covered times

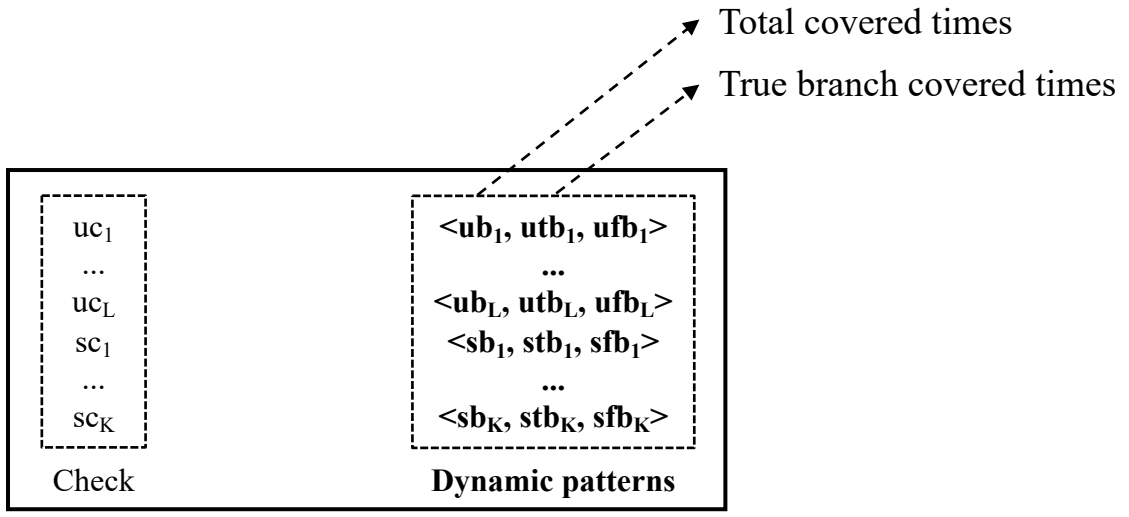


Design: dynamic pattern capturing

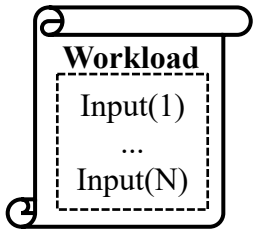


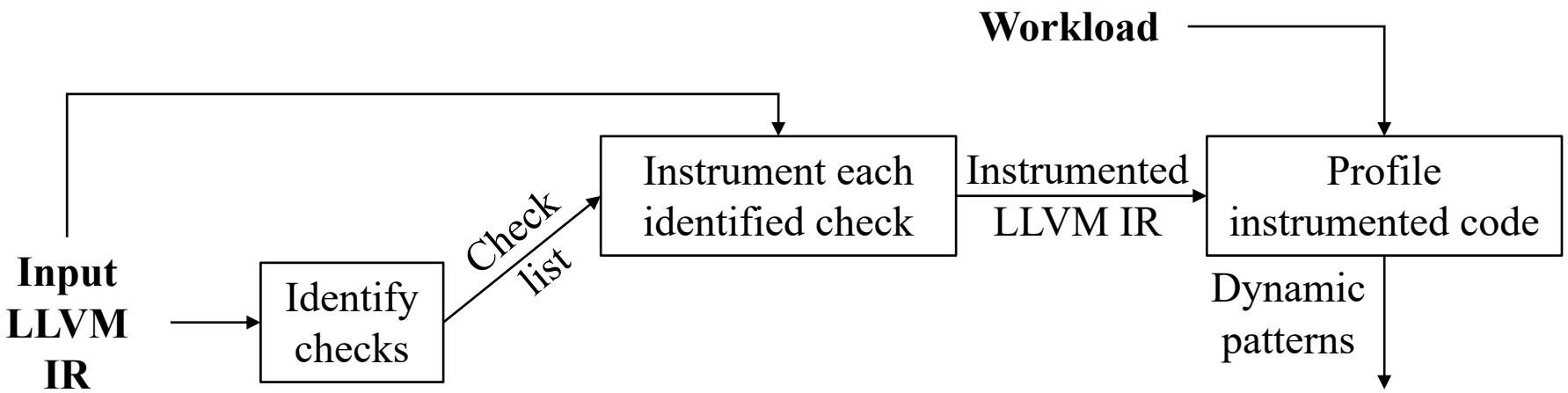



```
%o = icmp cond %a, %b
br i1 %o, label %bb1, label %bb2
```

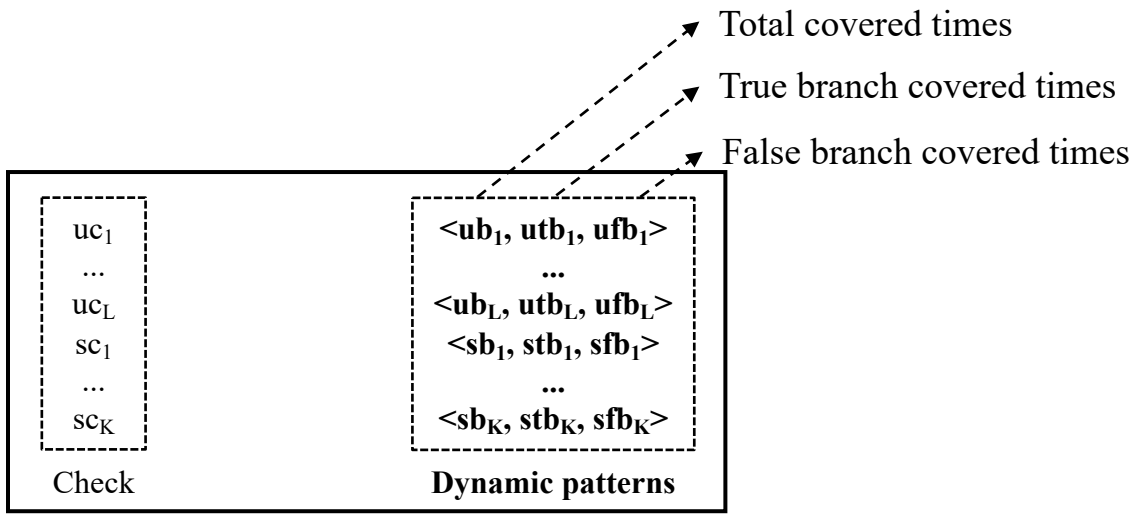


Design: dynamic pattern capturing

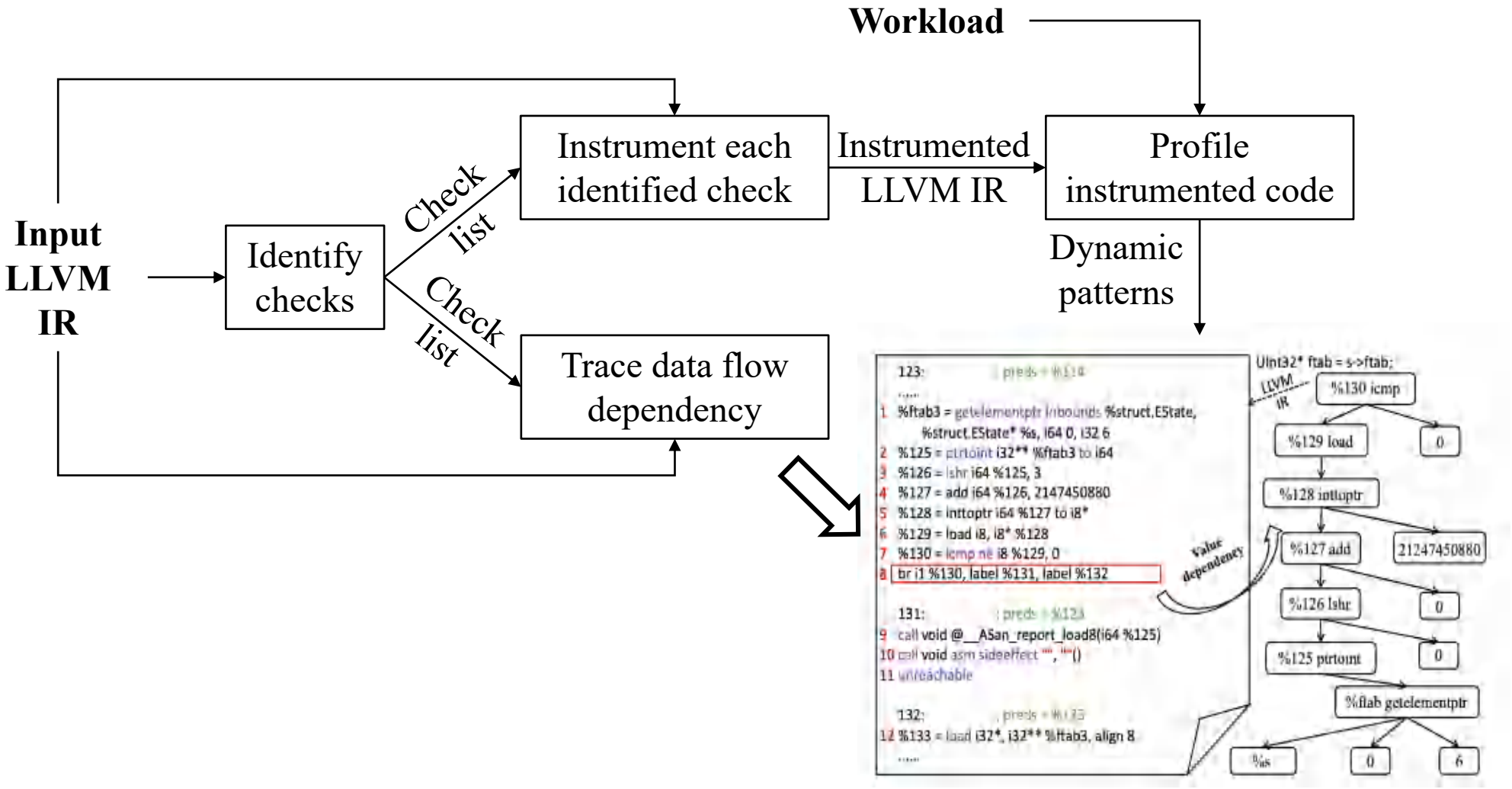




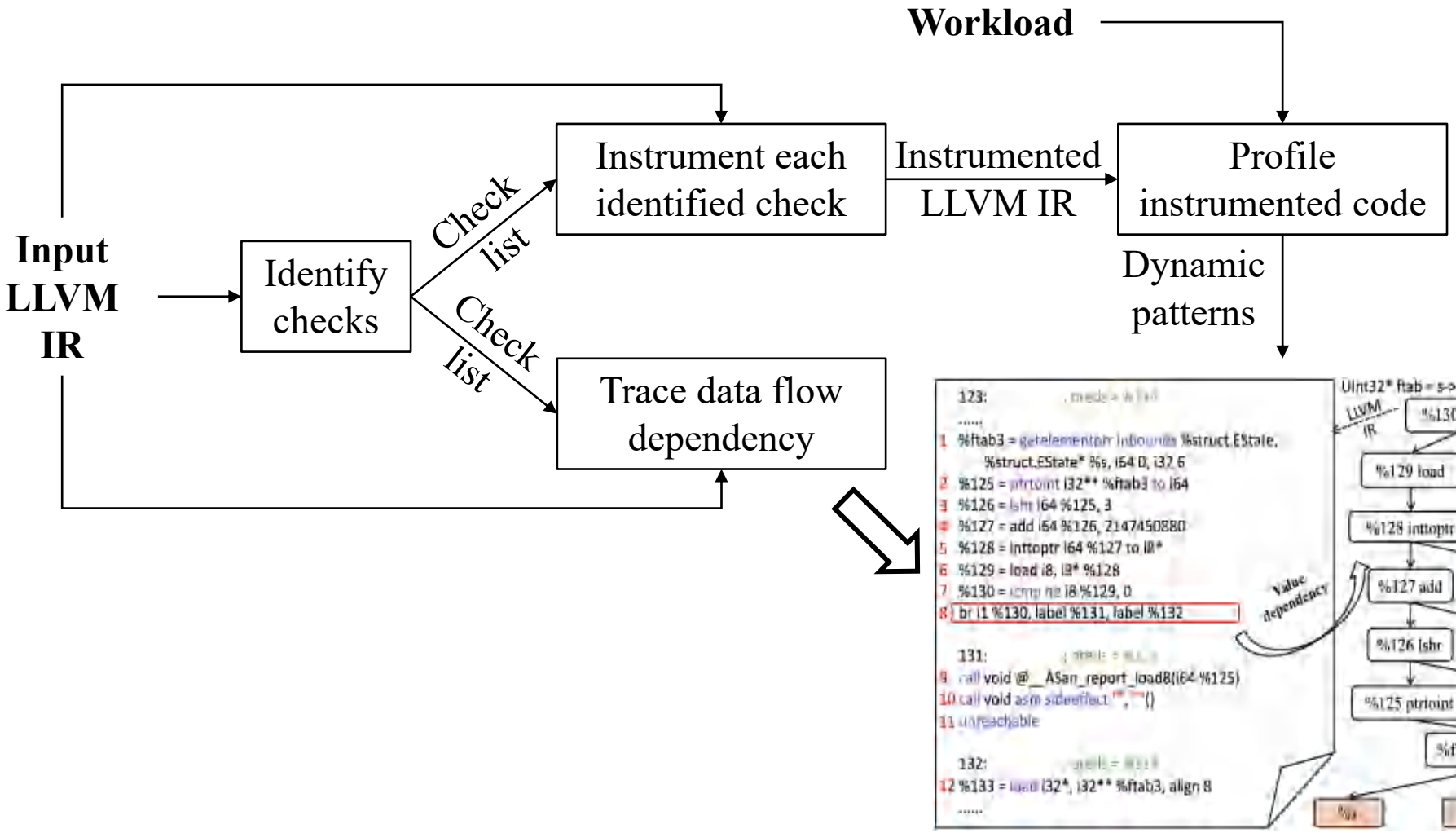

```
%o = icmp cond %a, %b
br i1 %o, label %bb1, label %bb2
```



Design: static pattern capturing

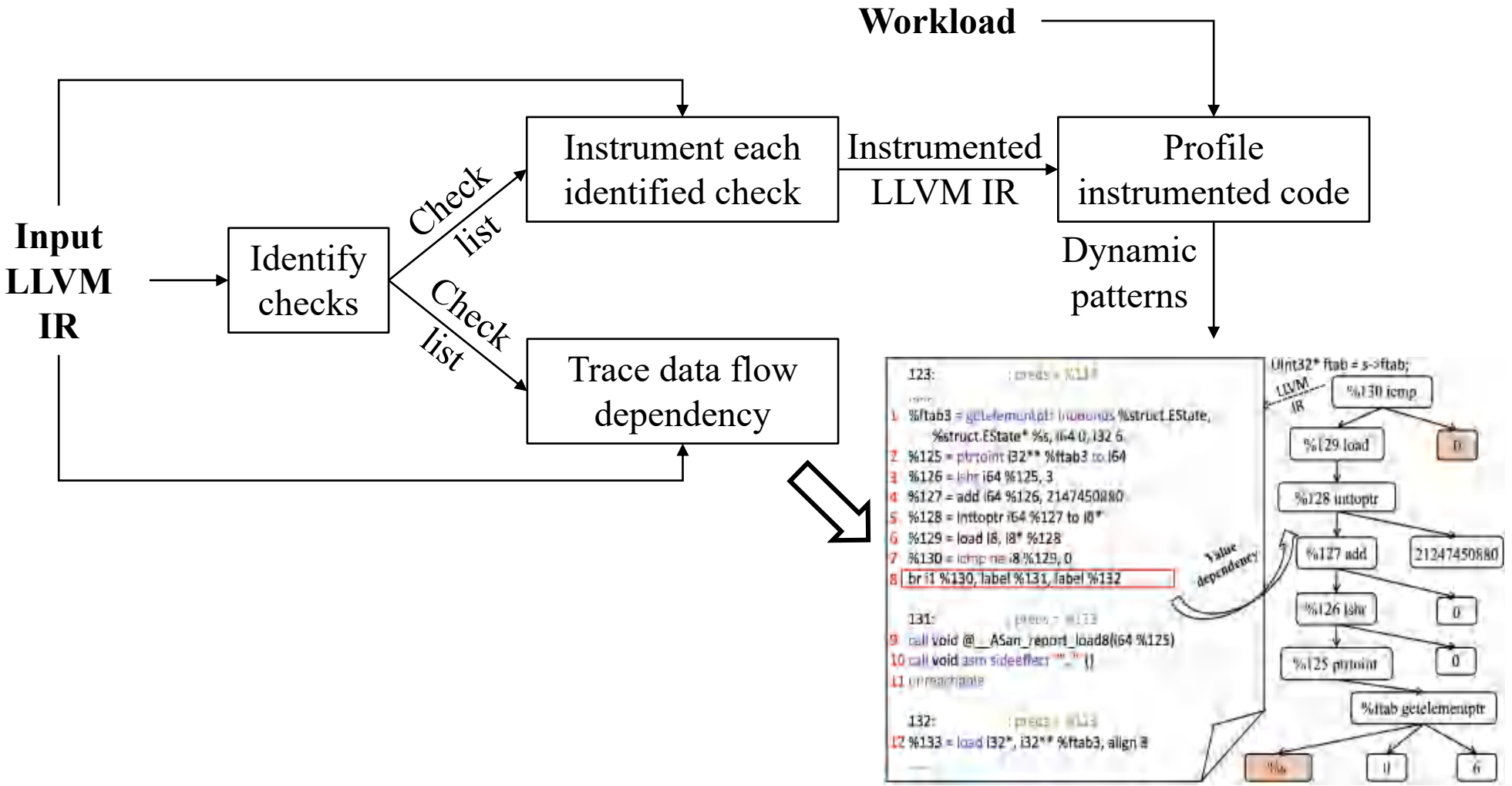


Design: static pattern capturing



L0: gather all leaf nodes

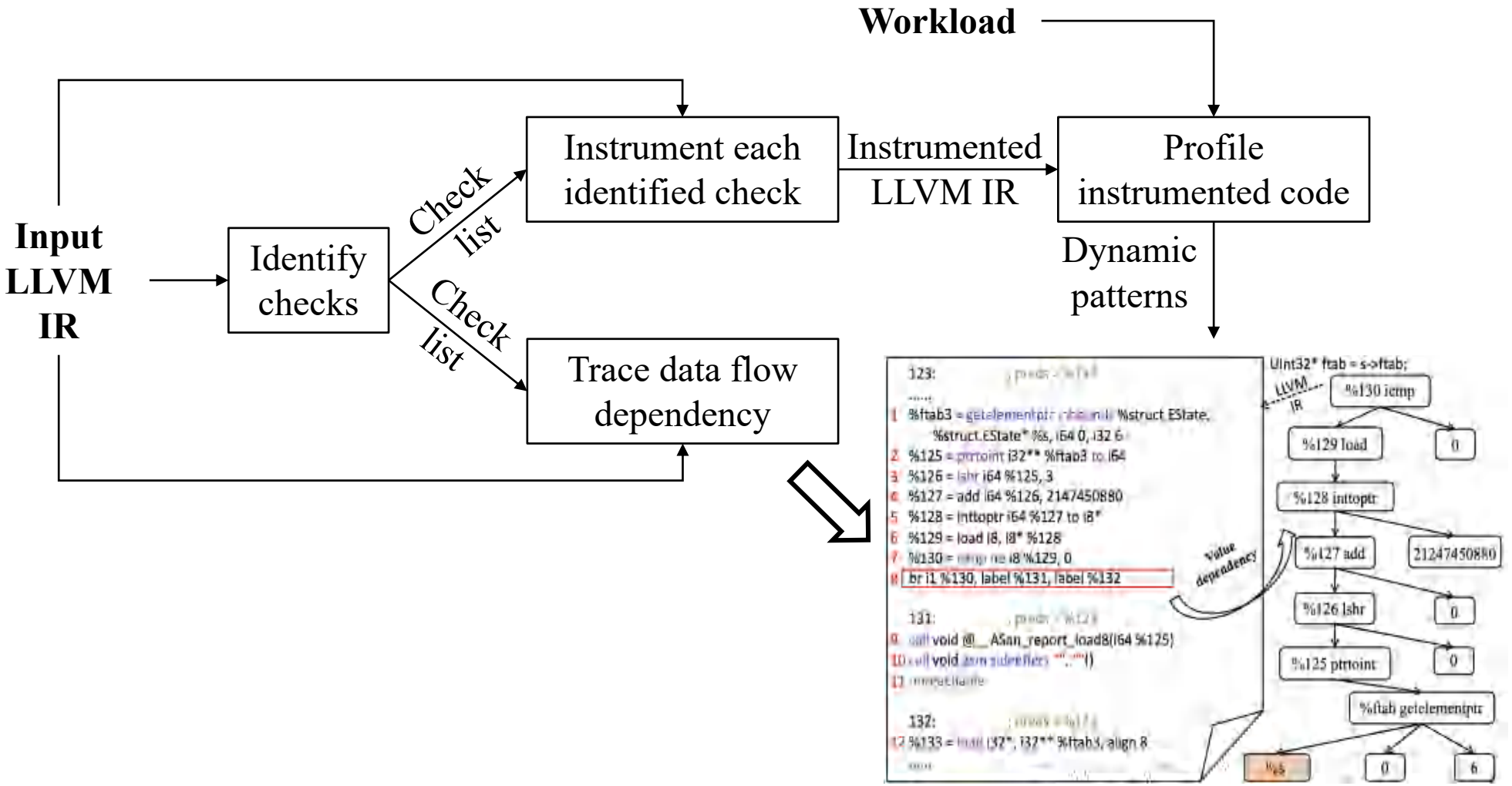
Design: static pattern capturing



L0: gather all leaf nodes

L1: remove all constants except those in the comparison statement

Design: static pattern capturing

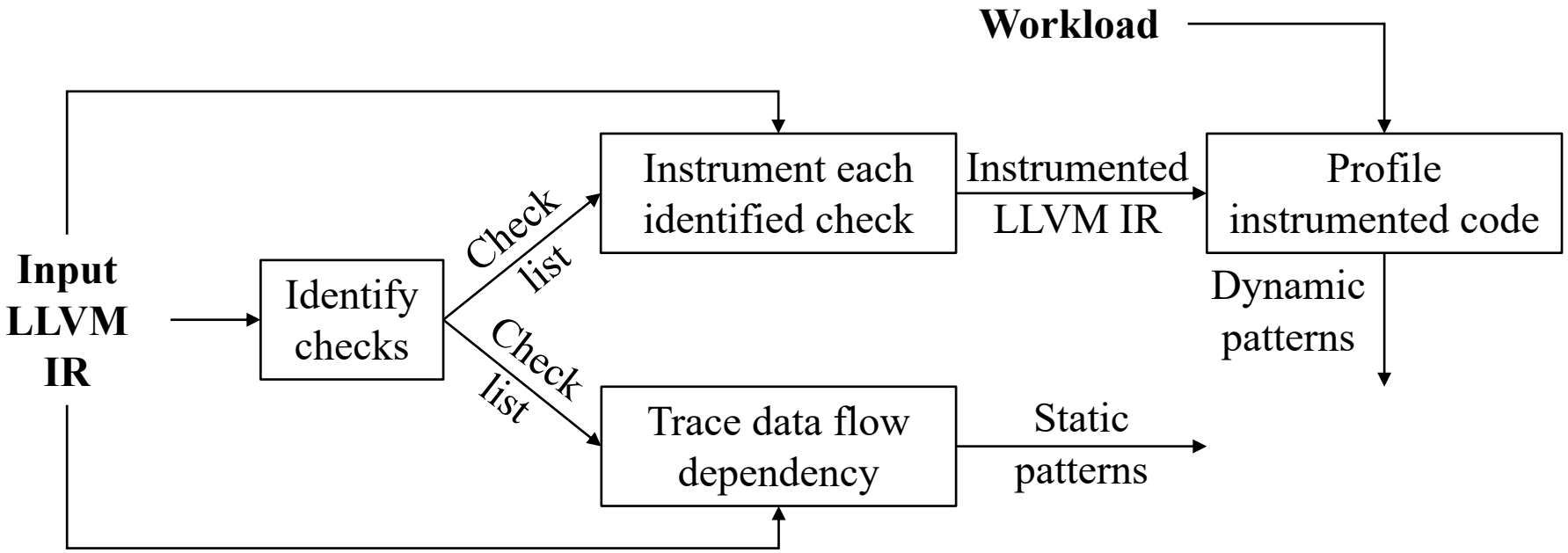


L0: gather all leaf nodes

L1: remove all constants except those in the comparison statement

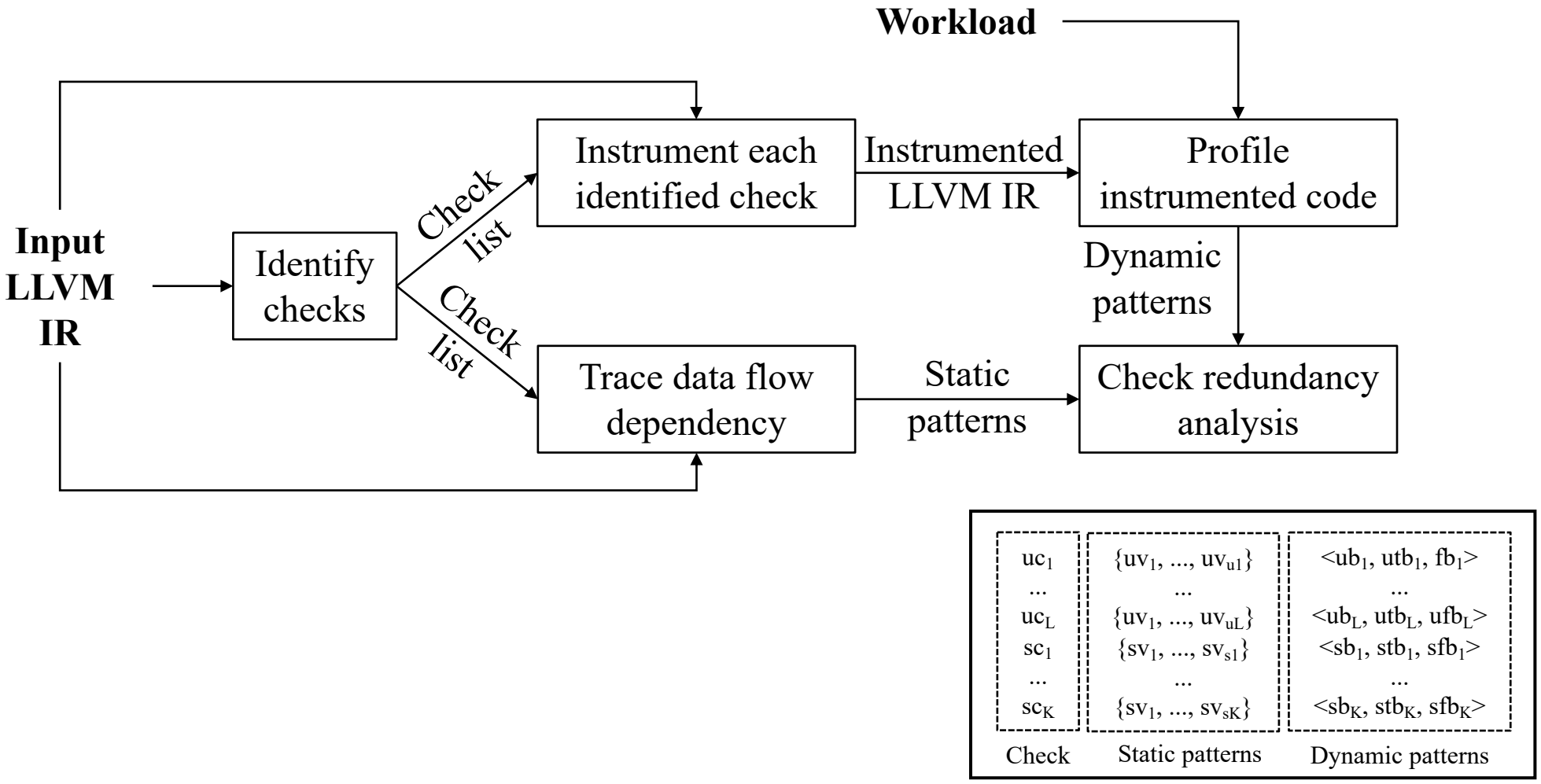
L2: remove all constants

Design: sanitizer check reduction

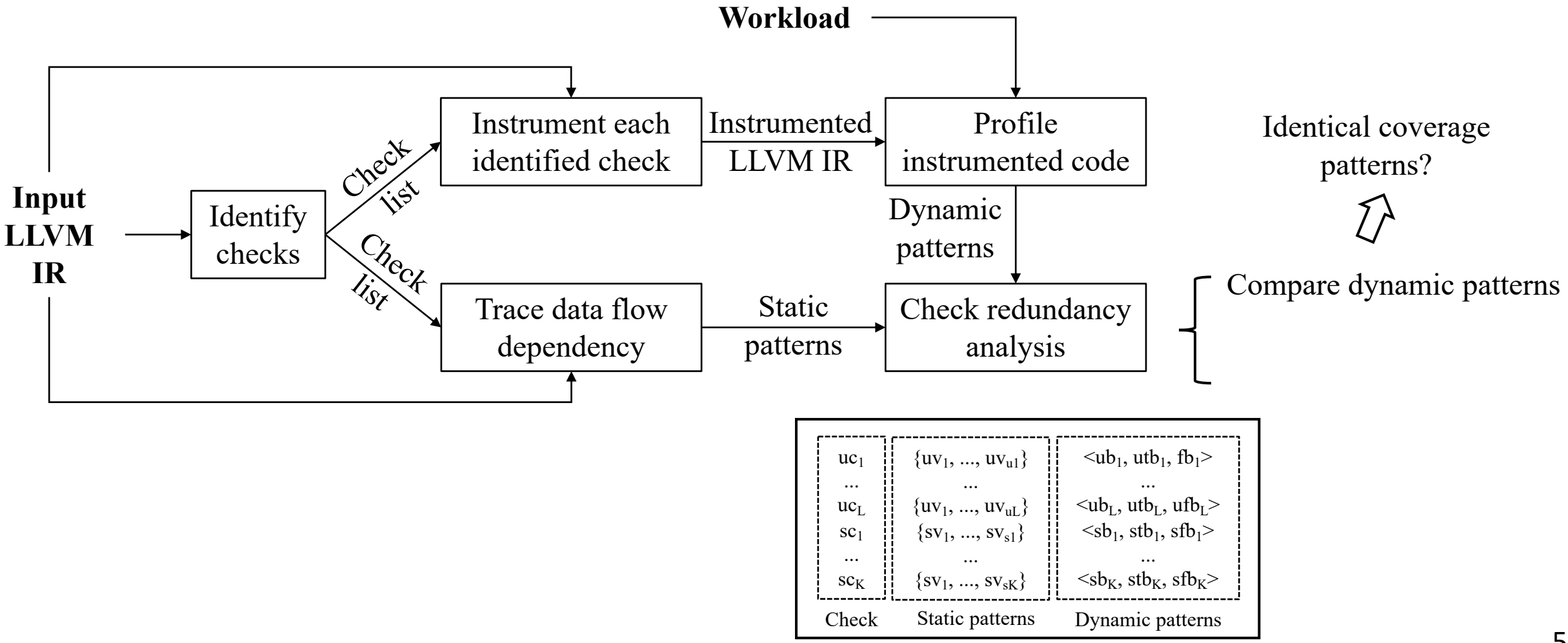


Check	Static patterns	Dynamic patterns
uc_1	$\{uv_1, ..., uv_{u1}\}$	$<ub_1, utb_1, fb_1>$
...	...	...
uc_L	$\{uv_1, ..., uv_{uL}\}$	$<ub_L, utb_L, ufb_L>$
sc_1	$\{sv_1, ..., sv_{s1}\}$	$<sb_1, stb_1, sfb_1>$
...	...	...
sc_K	$\{sv_1, ..., sv_{sK}\}$	$<sb_K, stb_K, sfb_K>$

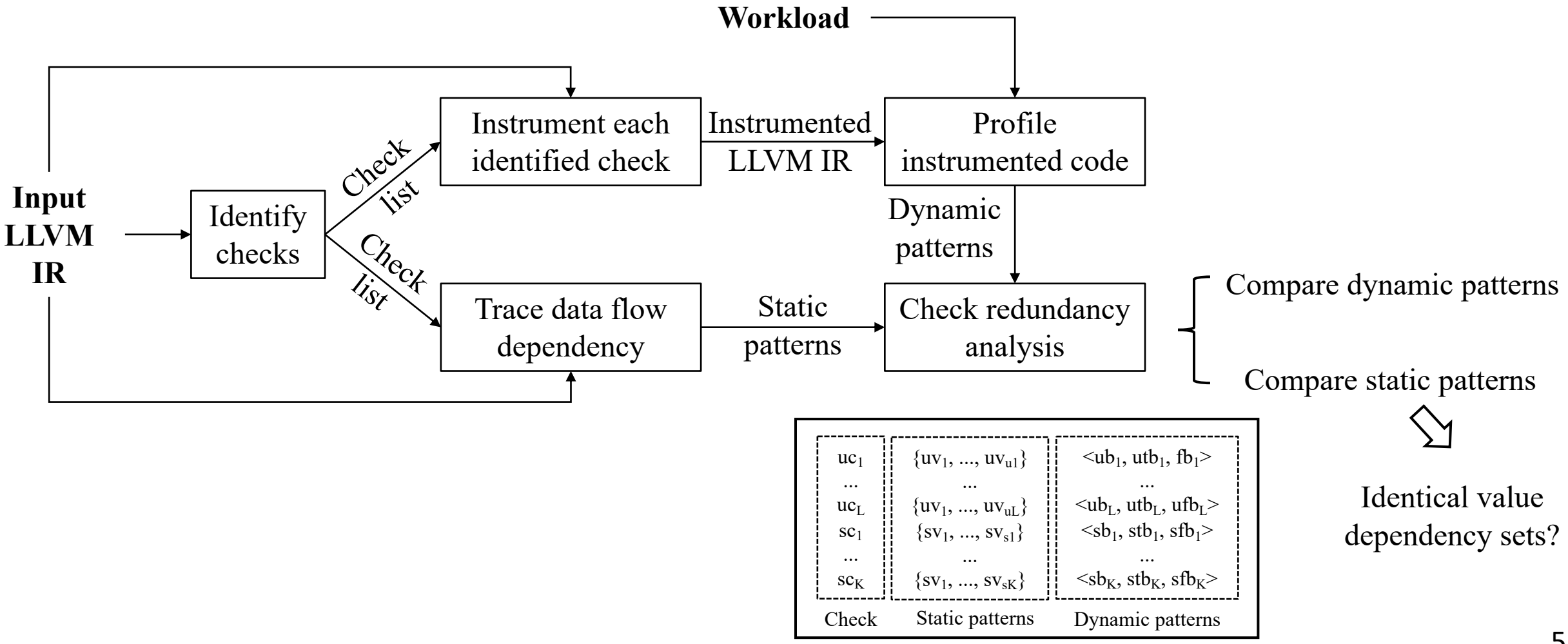
Design: sanitizer check reduction



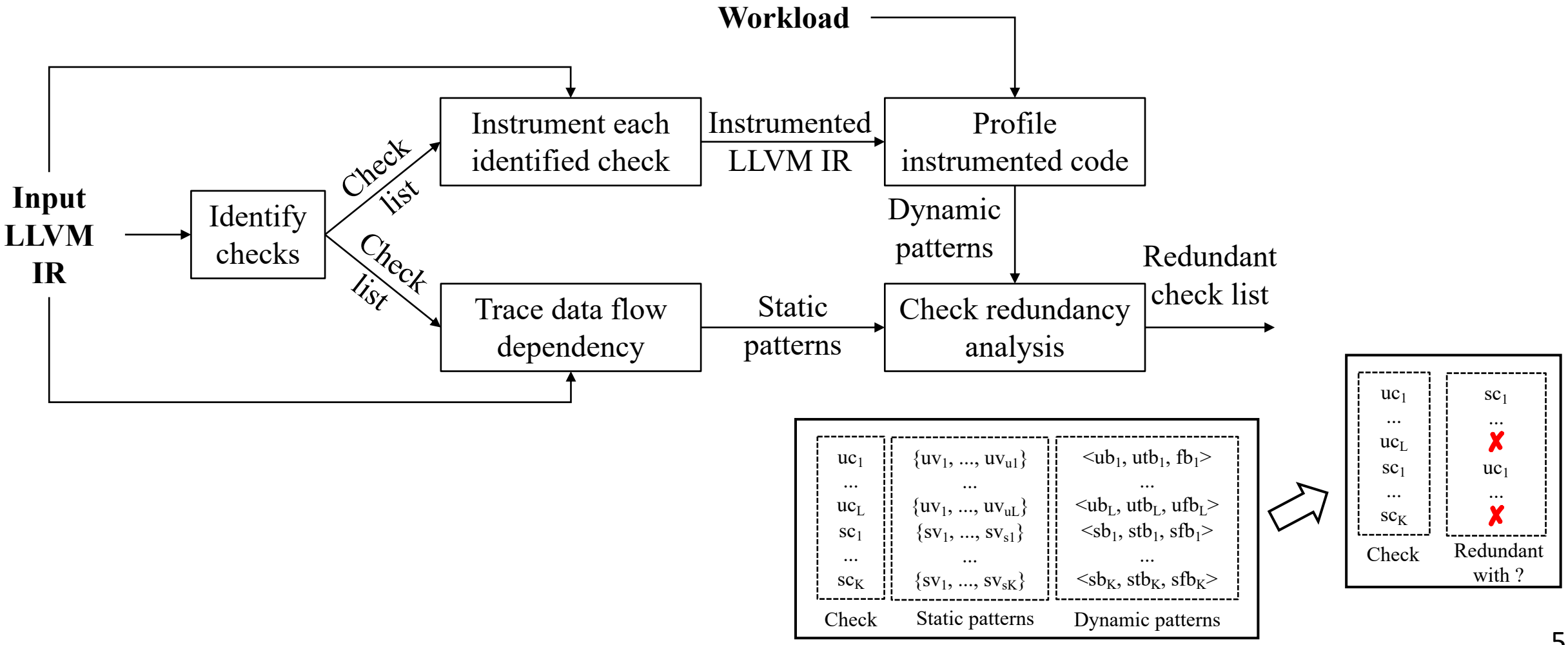
Design: sanitizer check reduction



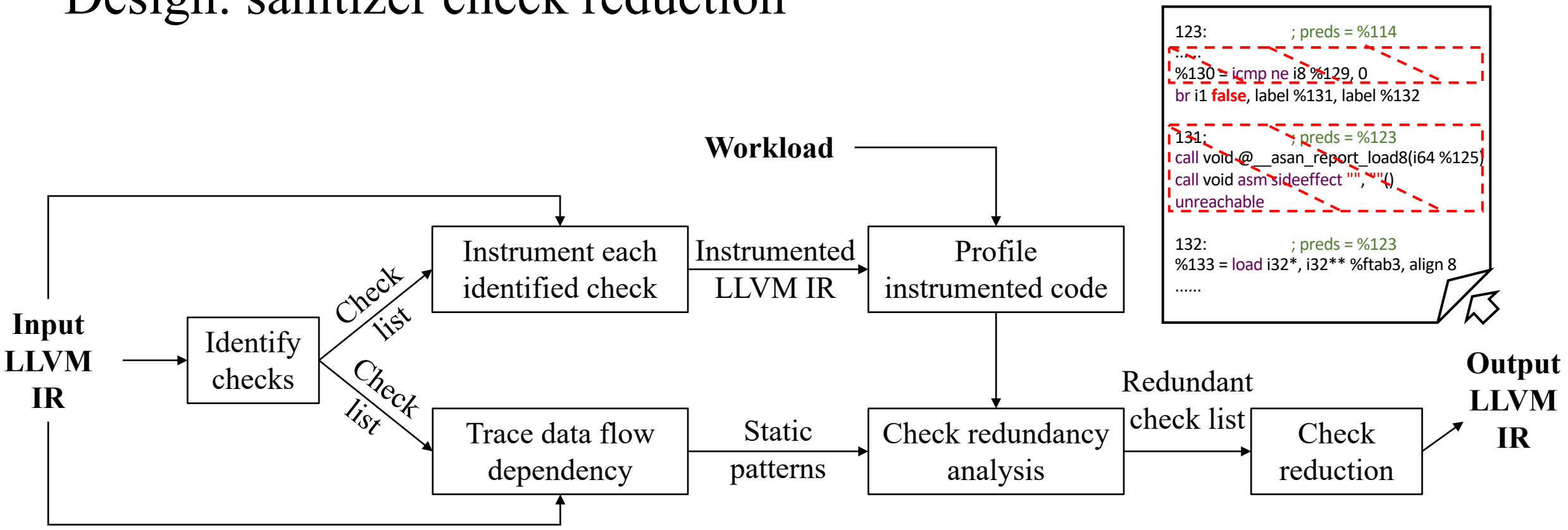
Design: sanitizer check reduction



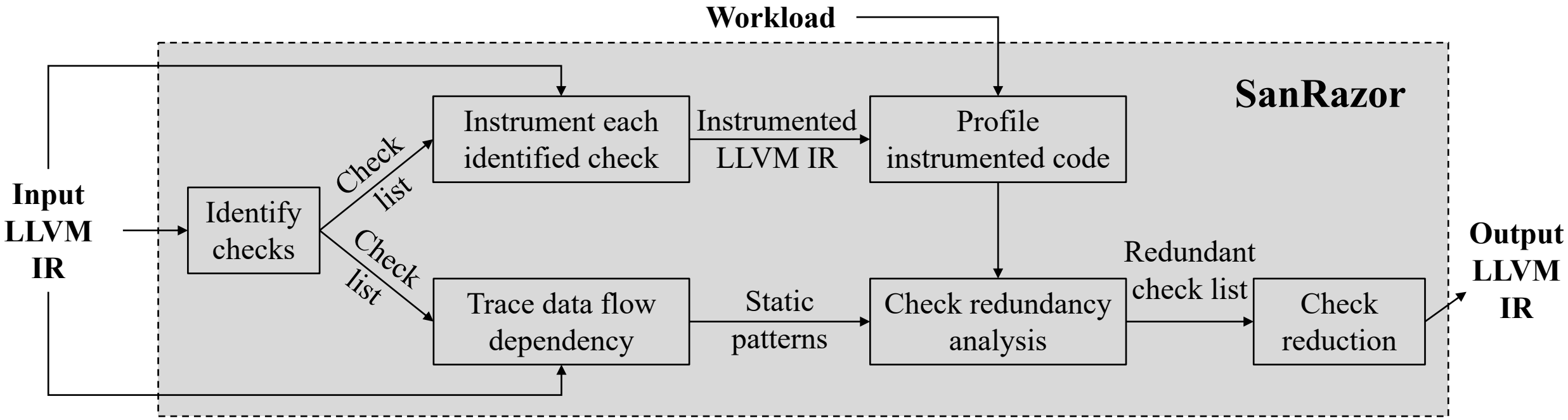
Design: sanitizer check reduction



Design: sanitizer check reduction



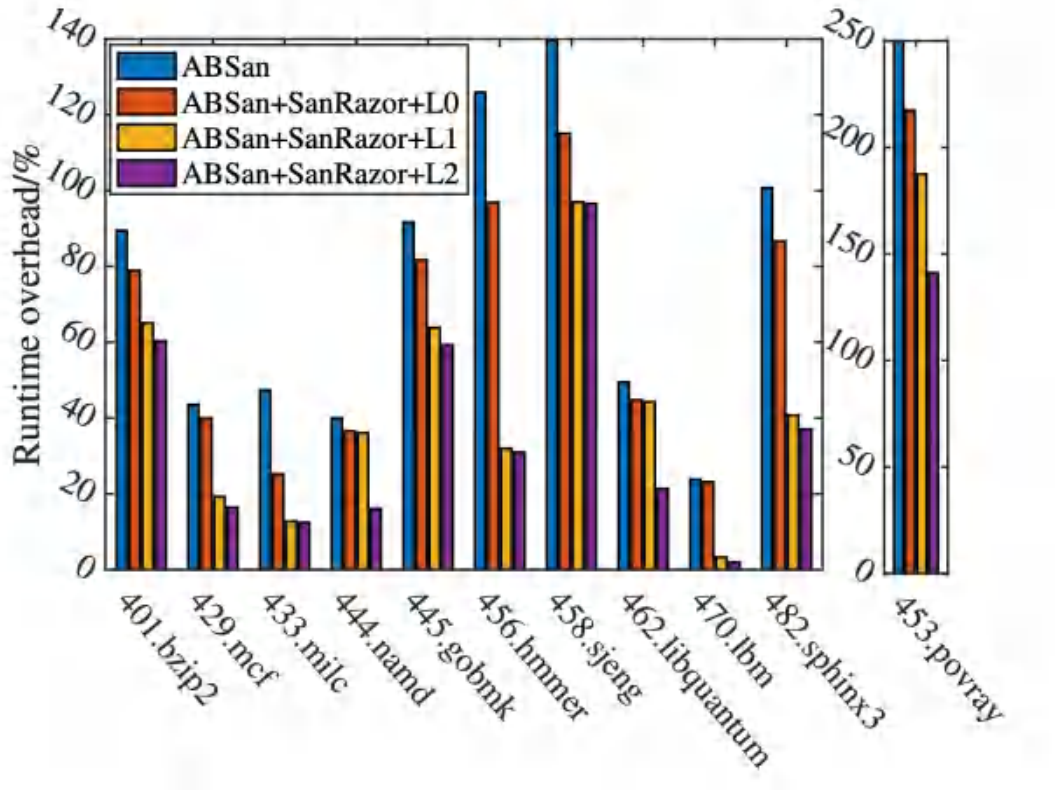
Design and implementation

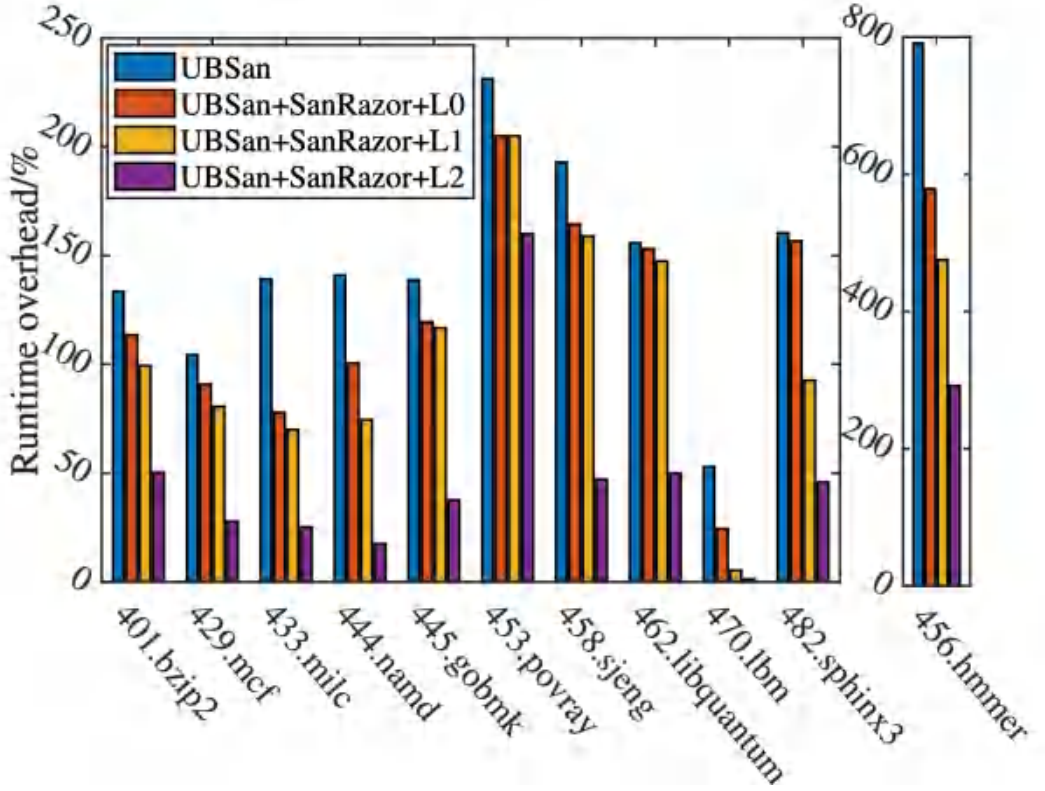


A general framework for effectively removing likely redundant sanitizer checks

Integrated into the LLVM framework → **SanRazor-clang**

Evaluation: cost study





Runtime overhead (geo-mean)

74% ⟶ **28%** - 62%

160% ⟶ **37%** - 124%

Evaluation: cost study

M1: number of removed sanitizer checks
M2: saved CPU cycles by reducing sanitizer checks

Benchmark	ASan-M_1			ASan-M_2			UBSan-M_1			UBSan-M_2		
	L0	*L1*	*L2*	*L0*	*L1*	*L2*	*L0*	*L1*	*L2*	*L0*	*L1*	*L2*
401.bzip2	22.4%	54.4%	58.1%	4.3%	30.3%	34.2%	38.7%	54.8%	66.0%	27.3%	37.9%	68.1%
429.mcf	10.2%	53.0%	60.9%	3.0%	46.6%	60.1%	35.0%	51.8%	76.2%	37.8%	47.6%	86.0%
445.gobmk	5.2%	23.4%	26.6%	7.2%	33.7%	41.0%	12.6%	21.6%	51.3%	21.4%	23.3%	73.9%
456.hmmer	5.9%	11.7%	13.1%	14.4%	70.3%	70.4%	8.2%	11.0%	14.8%	49.2%	60.7%	78.3%
458.sjeng	5.9%	12.6%	13.4%	4.4%	34.4%	36.7%	12.1%	18.3%	51.0%	20.7%	25.2%	79.2%
462.libquantum	7.4%	16.3%	22.6%	0.8%	1.4%	2.4%	12.7%	15.6%	26.9%	0.8%	0.8%	58.8%
433.milc	23.5%	32.5%	33.5%	35.8%	80.9%	82.7%	27.6%	42.2%	54.6%	51.0%	60.6%	83.6%
444.namd	6.4%	18.9%	24.0%	10.2%	29.8%	57.7%	8.7%	16.0%	26.2%	40.4%	54.1%	84.8%
470.lbm	1.6%	68.5%	72.1%	0.0%	88.7%	92.5%	17.7%	48.2%	51.3%	46.0%	92.5%	97.6%
482.sphinx3	10.7%	27.1%	32.5%	2.5%	56.9%	58.3%	18.2%	23.7%	40.0%	11.9%	45.3%	67.2%
453.povray	7.2%	9.5%	21.2%	2.3%	12.1%	69.1%	11.1%	11.9%	22.6%	22.6%	24.0%	75.5%

SanRazor eliminates up to 30% ASan checks and save 41% CPU cycles

SanRazor eliminates up to 39% UBSan checks and save 77% CPU cycles

Evaluation: vulnerability detectability study

Select 38 CVEs from 10 commonly-used programs

Software	CVE			SanRazor			ASAP			
	Type	Sanitizer	N	*L0*	*L1*	*L2*	$Budget_0$	$Budget_1$	$Budget_2$	$Budget_3$
autotrace	signed integer overflow	UBSan	8	8	8	6	6	8	8	8
	left shift of 128 by 24	UBSan	1	1	1	1	1	1	1	1
	heap buffer overflow	ASan	10	10	10	10	0	8	2	2
imageworsener	divide-by-zero	UBSan	2	2	2	2	2	2	2	2
	index out of bounds	UBSan	1	1	1	0	1	1	1	1
lame	divide-by-zero	UBSan	1	1	1	1	1	1	1	1
	heap buffer overflow	ASan	1	1	1	1	0	1	0	0
zziplib	heap buffer overflow	ASan	2	2	2	2	0	0	0	0
libzip	user after free	ASan	1	1	1	0	0	1	1	1
graphicsmagick	heap use after free	ASan	1	1	1	1	0	1	1	1
libtiff	heap buffer overflow	ASan	2	2	2	2	0	2	2	2
	stack buffer overflow	ASan	1	1	1	1	1	1	1	1
	divide-by-zero	UBSan	1	1	1	1	1	1	1	1
jasper	left shift of negative value	UBSan	1	1	1	1	1	1	1	1
potrace	heap buffer overflow	ASan	1	1	1	1	0	1	1	0
mp3gain	stack buffer overflow	ASan	2	2	2	2	0	2	0	0
	global buffer overflow	ASan	1	1	1	1	0	0	0	0
	null pointer dereference	ASan	1	1	0	0	1	1	1	1
In total			38	38	37	33	15	33	24	23

SanRazor detects at least **33 out of the 38 CVEs**

Application scenario

- Accelerate sanitization enabled programs in production usage
  - Keep the most useful checks in terms of discovering unique problems

Application scenario

- Accelerate sanitization enabled programs in production usage
  - Keep the most useful checks in terms of discovering unique problems

- Combined with complementary approaches to further reduce overhead
  - SanRazor are generally orthogonal to other sanitizer tools
  - E.g. combining SanRazor with ASAP reduces the runtime cost to only 7% with a reasonable tradeoff of security

Summary

- Present SanRazor, a novel and practical tool for sanitizer check reduction
- SanRazor is designed as a hybrid approach to remove likely redundant checks
- Evaluation shows that SanRazor effectively lowers the overhead caused by sanitizer, while still retaining high vulnerability detection capability

Thanks for listening!

Contact: jiangzha@usc.edu

Github repository: https://github.com/SanRazor-repo/SanRazor