Value and Allocation Sensitivity in Static Python Analyses

Raphaël Monat, Abdelraouf Ouadjaout, Antoine Miné

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https://rmonat.fr/soap20/

Introduction

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Python, from a PL perspective

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- Self-modification,
- `eval`.

Based on a previous work focusing on sound type analysis[1].

[1]Monat, Ouadjaout, and Miné. "Static Type Analysis by Abstract Interpretation of Python Programs". ECOOP'20.
[2]Journault et al. "Combinations of reusable abstract domains for a multilingual static analyzer". VSTTE'19.

Static Analysis of Python

Based on a previous work focusing on sound type analysis[1].

Goal: detect all potential runtime errors (i.e, uncaught exceptions).

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Implementation: Mopsa[2], easing static analysis development through modular, reusable domains (ex: shared domains for C and Python).

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Studied Research Questions

- **Type or Value Analysis?**
  - Cost of adding value sensitivity?
  - Precision gain?
- Heap Abstraction using the Recency Abstraction[3]
  - Best policy to group/abstract addresses?
  - Policy depending on the value-sensitivity?
- Abstract Garbage Collection
  - Is the gain provided sufficient to offset its cost?

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Type and Value Analyses of Python

Type Analysis

- By induction on the syntax
- Context-sensitive
- Flow-sensitive

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- 4 `ValueError`s
- l: list of `Task`s, having an integer weight
- i, m: integers
- `IndexError`
- `NameError` (over i)
- `ZeroDivisionError`

$\Longrightarrow$ 7 false alarms

Value Analysis

Refinement of the type analysis.

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- len(l)$= 4$
- $0 \leq i < 4$
- valid list access

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- len(l)$= 4$
- $i = 3$

$\Longrightarrow$ No false alarm!

Related Work: Static Analyses of Python

- Type Analyses:
  - Dataflow analysis by Fritz and Hage[4].
  - SMT-based type inference[5].
  - Pytype, a tool used by Google[6].
- Value Analysis by Fromherz et al[7].

[4] Fritz and Hage. "Cost versus precision for approximate typing for Python". PEPM.
[5] Hassan et al. "MaxSMT-Based Type Inference for Python 3". CAV.
[6] Kramm et al. Pytype.
[7] Fromherz, Ouadjaout, and Miné. "Static Value Analysis of Python Programs by Abstract Interpretation". NFM.

Experimental Evaluation

Name	LOC	Type Analysis					Value Analysis				
		Time	Mem.	Exceptions detected			Time	Mem.	Exceptions detected		
				Type	Index	Key			Type	Index	Key
scimark	416	1.4s	12MB	1	1	0	3.4s	27MB	1	**0**	0
richards	426	13s	112MB	1	4	0	17s	149MB	1	**2**	0
unpack	458	8.3s	7MB	0	0	0	9.4s	6MB	0	0	0
go	461	27s	345MB	33	20	0	2.0m	1.4GB	33	20	0
hexiom	674	1.1m	525MB	0	46	3	4.7m	3.2GB	0	**21**	3
regex	1792	23s	18MB	0	2053	0	1.3m	56MB	0	**145**	0
process	1417	10s	64MB	7	7	1	12s	85MB	7	**4**	1
choose	2562	1.1m	1.6GB	12	22	7	2.9m	3.7GB	12	**13**	7
Total	9294	4.0m	2.8GB	59	2214	12	13m	9.1GB	59	228	12

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unpack	458	8.3s	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0
go	461	27s	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33	20	0
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Conclusion

The Value Analysis:

- does not remove false type alarms,
- significantly reduces index errors,
- is $\simeq 3\times$ costlier.

Variable-Policy Recency Abstraction

Presenting the Recency Abstraction

Goal: Allow a precise analysis of object initialization, assuming it happens just after allocation.

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Means: Twofold partitioning:

1. by allocation site $l \in \mathbb{L}$
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   - $(l, \boldsymbol{r})$: most recent allocation (with strong updates)
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First try: type analysis $\rightsquigarrow$
replace $l \in \mathbb{L}$ with Python types $t \in \mathbb{T}$.

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Variable Allocation Policies

The type-based partitioning may be unprecise in some cases:

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Variable Allocation Policies: type-based **and** location-based partitioning.
Parameterized by the user given the type. Details in the paper.

Experimental Evaluation

Name	Type Only Partitioning			Type + Loc. Partitioning		
	Time	Mem.	⚠	Time	Mem.	⚠
chaos	**30s**	**197MB**	30	2.4m	1.2GB	**15**
rayt	27s	171MB	28	**4.5s**	**74MB**	**7**
scimark	3.4s	27MB	4	**3.0s**	27MB	**3**
richards	**17s**	**149MB**	5	69m	15GB	5
unpack	**9.4s**	6MB	0	9.6s	6MB	0
go	2.0m	1.4GB	57	**1.7m**	**1.2GB**	57
hexiom	4.7m	3.2GB	27	**4.2m**	3.2GB	27
regex	**1.3m**	**56MB**	145	3.6m	85MB	145
process	12s	85MB	15	**11s**	**74MB**	**13**
choose	**2.9m**	**3.7GB**	68	3.1m	4.3GB	**63**
Total	13m	9.1GB	392	87m	25GB	359

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richards	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
unpack	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Total	13m	9.1GB	392	87m	25GB	359

Conclusion

In most cases:

- Type-only partitioning is more efficient
- But it induces a 9% alarm overhead

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```
1 def f():
2   l = [Task(2), Task(1), Task(4), Task(5)]
3   return sum([x.weight for x in l])
4
5 s = f()
6 [...]
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(Task, r), (Task, o) still exist after line 6.

We implemented a tracing AGC, reducing abstract state's size.

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(Task, r), (Task, o) still exist after line 6.

We implemented a tracing AGC, reducing abstract state's size.

AGC *may* improve precision (example in the paper);
it does not happen in our benchmarks though.

Related Work

- Analysis of higher-order languages: tracing AGC[8], reference-counting AGC[9]. Reduces analysis time by an order of magnitude. May improve the precision.
- Analysis of object-oriented languages: TAJS[10]: reduces memory.

[8] Jagannathan et al. "Single and Loving It: Must-Alias Analysis for Higher-Order Languages". POPL; Might and Shivers. "Improving flow analyses via ΓCFA: abstract garbage collection and counting". ICFP.

[9] Es, Stiévenart, and Roover. "Garbage-Free Abstract Interpretation Through Abstract Reference Counting". ECOOP.

[10] Jensen, Møller, and Thiemann. "Type Analysis for JavaScript". SAS.

Experimental Evaluation

Name	Without AGC		With AGC		Rel. Impr.	
	Time	Mem.	Time	Mem.	Time	Mem.
chaos	10s	64MB	7.4s	42MB	28%	34%
rayt	17s	74MB	14s	74MB	16%	0%
scimark	1.5s	13MB	1.4s	12MB	5%	8%
richards	16s	227MB	13s	112MB	21%	51%
unpack	10s	9MB	8.3s	7MB	19%	22%
go	38s	604MB	27s	345MB	31%	43%
hexiom	2.2m	1.1GB	1.1m	525MB	49%	50%
regex	30s	24MB	23s	18MB	23%	25%
process	14s	85MB	10s	64MB	28%	25%
choose	2.0m	3.2GB	1.1m	1.6GB	43%	50%
Total	6.5m	5.4GB	4.0m	2.8GB	38%	47%

Experimental Evaluation

Name	Without AGC		With AGC		Rel. Impr.	
	Time	Mem.	Time	Mem.	Time	Mem.
chaos	10s	64MB	7.4s	42MB	28%	34%
rayt	17s	74MB	14s	[illegible]	[illegible]	[illegible]%
scimark	1.5[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]%
richards	16[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]%
unpack	10[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]%
go	38[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]%
hexiom	2.2m	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]%
regex	30s	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]%
process	14s	[illegible]	10s	64MB	28%	25%
choose	2.0m	3.2GB	1.1m	1.6GB	43%	50%
Total	6.5m	5.4GB	4.0m	2.8GB	38%	47%

Conclusion

- 38% analysis time improvement
- 47% less memory used
- less than 6% time spent in AGC
- no precision improvement

Conclusion

Conclusion

- Types or values?

Conclusion

- Types or values? Your choice!

Conclusion

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- Various allocation policies, depending on the value-sensitivity.

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- Various allocation policies, depending on the value-sensitivity.
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Future work:

Conclusion

- Types or values? Your choice!
- Various allocation policies, depending on the value-sensitivity.
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Future work:

- Dynamic allocation policies.

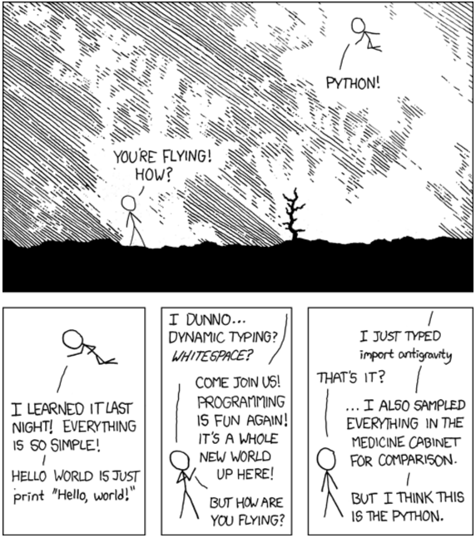
Conclusion

- Types or values? Your choice!
- Various allocation policies, depending on the value-sensitivity.
- Abstract garbage collection is really beneficial.

Future work:

- Dynamic allocation policies.
- Scaling to more realistic Python applications.

Thank you! Questions?



xkcd.com/353/