Learning the Linux Kernel Configuration Space: Results and Challenges

Mathieu Acher

Embedded Linux Conference Europe

Learning the Linux Kernel Configuration Space: Results and Challenges

Prof. Mathieu Acher (University of Rennes 1, Inria/IRISA)

@acherm

THE LINUX FOUNDATION

Talk given at ELC 2019 (30 october 2019)

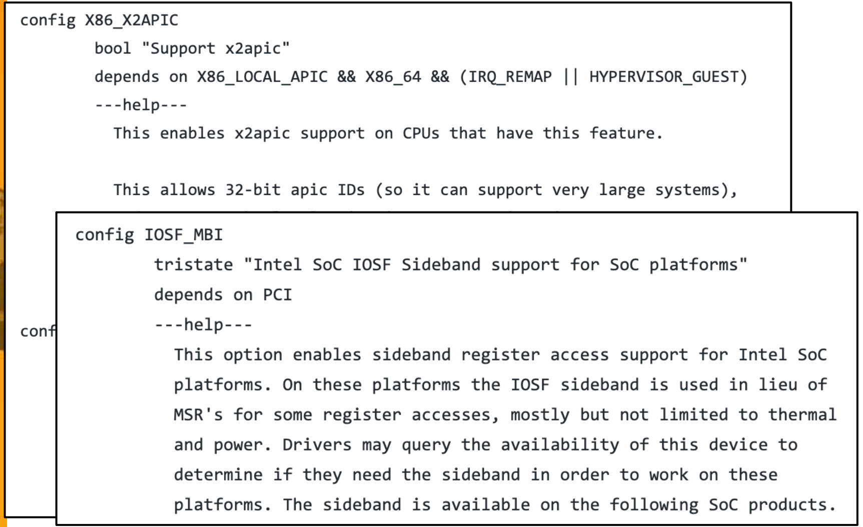
- Abstract: “Given a configuration, can humans know in advance the size, the compilation time, or the boot time of a Linux kernel? Owing to the huge complexity of Linux (there are more than 15000 options with hard constraints and subtle interactions), machines should rather assist contributors and integrators in mastering the configuration space of the kernel. In this talk, Mathieu Acher will introduce TuxML an OSS tool based on Docker/Python to massively gather data about thousands of kernel configurations. Mathieu will describe how 200K+ configurations have been automatically built and how machine learning can exploit this information to predict properties of unseen Linux configurations, with different use cases (identification of influential/buggy options, finding of small kernels, etc.) The vision is that a continuous understanding of the configuration space is undoubtedly beneficial for the Linux community, yet several technical challenges remain in terms of infrastructure and automation.”
- This research was funded by the ANR-17-CE25-0010-01 VaryVary project
  - https://varyvary.github.io/

Preprints (feedbacks welcome!)

- Learning From Thousands of Build Failures of Linux Kernel Configurations
  - Mathieu Acher, Hugo Martin, Juliana Alves Pereira, Arnaud Blouin, Djamel Eddine Khelladi, Jean-Marc Jézéquel
  - https://hal.inria.fr/hal-02147012
- Learning Very Large Configuration Spaces: What Matters for Linux Kernel Sizes
  - Mathieu Acher, Hugo Martin, Juliana Pereira, Arnaud Blouin, Jean-Marc Jézéquel, Djamel Eddine Khelladi, Luc Lesoil, Olivier Barais
  - https://hal.inria.fr/hal-02314830

Linux everywhere since

highly configurable



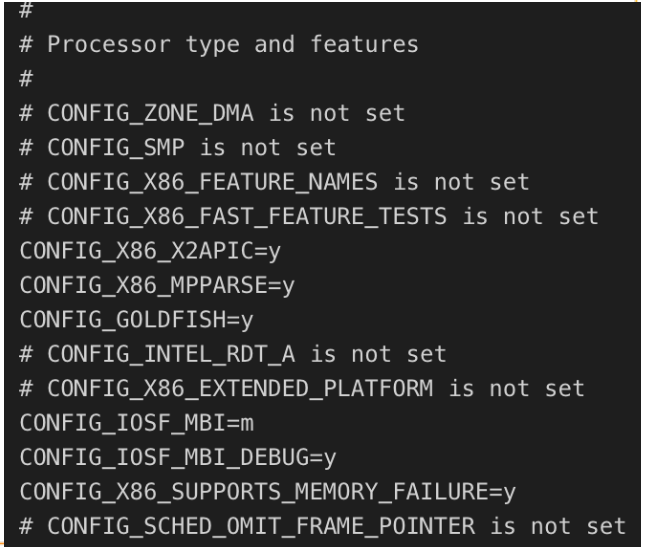
```
config X86_X2APIC
        bool "Support x2apic"
        depends on X86_LOCAL_APIC && X86_64 && (IRQ_REMAP || HYPERVISOR_GUEST)
        ---help---
          This enables x2apic support on CPUs that have this feature.

          This allows 32-bit apic IDs (so it can support very large systems),
```

```
conf
```

```
config IOSF_MBI
        tristate "Intel SoC IOSF Sideband support for SoC platforms"
        depends on PCI
        ---help---
          This option enables sideband register access support for Intel SoC
          platforms. On these platforms the IOSF sideband is used in lieu of
          MSR's for some register accesses, mostly but not limited to thermal
          and power. Drivers may query the availability of this device to
          determine if they need the sideband in order to work on these
          platforms. The sideband is available on the following SoC products.
```

Kconfig files/doc



```
#
# Processor type and features
#
# CONFIG_ZONE_DMA is not set
# CONFIG_SMP is not set
# CONFIG_X86_FEATURE_NAMES is not set
# CONFIG_X86_FAST_FEATURE_TESTS is not set
CONFIG_X86_X2APIC=y
CONFIG_X86_MPPARSE=y
CONFIG_GOLDFISH=y
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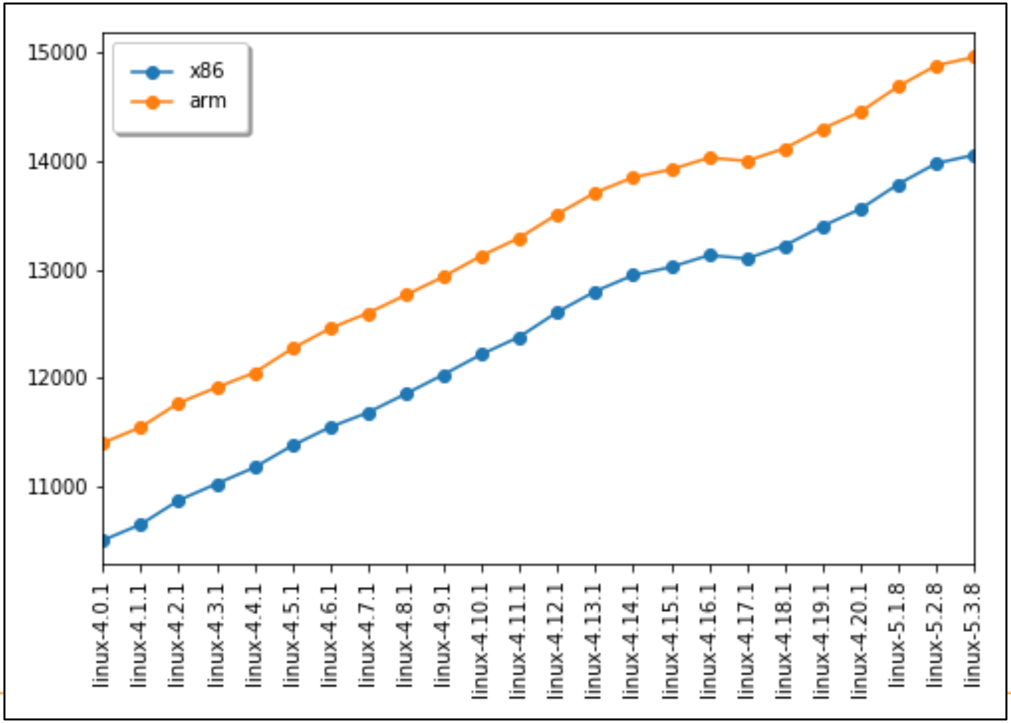
# CONFIG_X86_EXTENDED_PLATFORM is not set
CONFIG_IOSF_MBI=m
CONFIG_IOSF_MBI_DEBUG=y
CONFIG_X86_SUPPORTS_MEMORY_FAILURE=y
# CONFIG_SCHED_OMIT_FRAME_POINTER is not set
```

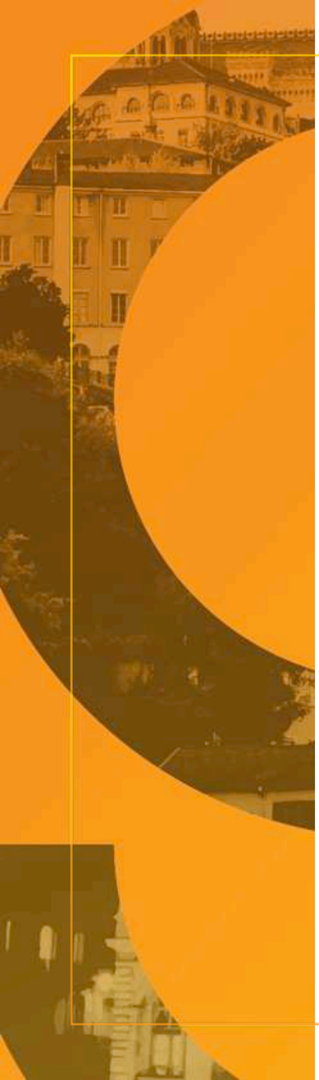
.config

15,000+ options



Configurations: Hell or Heaven?

Stop ou encore?



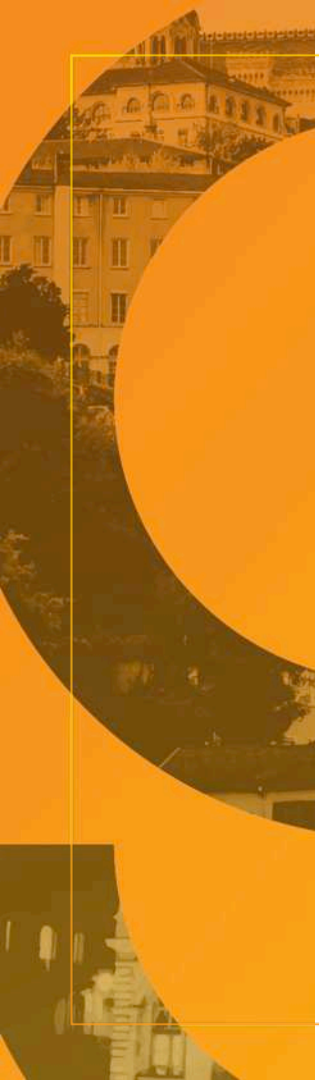
How to ensure that all configurations of the Linux kernel build/boot?

Many failures are due to buggy (combinations of) options

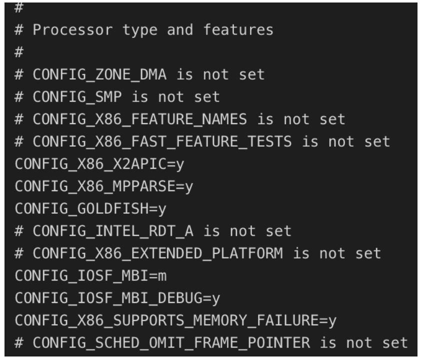
Devs/maintainers are struggling to track/fix bugs

Linus Torvalds: “random crazy user bugs” (random configurations are certainly a good subset)

Testing Linux kernels (on few configs):
(e.g., 0-day/KernelCI)



Given a kernel configuration, what's its size/boot time?



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```

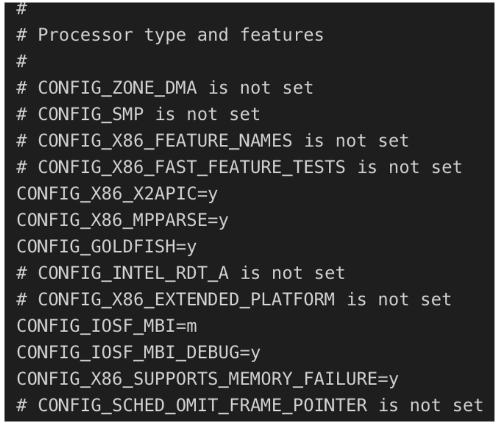
Who knows what's the effect of options?

Default configurations/options' values

Documentation (Kconfig)

Configurators

Effects of (combinations of) options on build status/boot/size/boot time/ performance/securi



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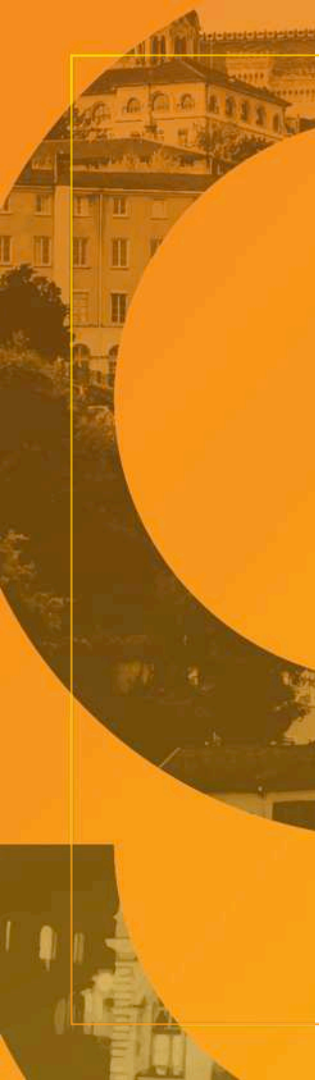
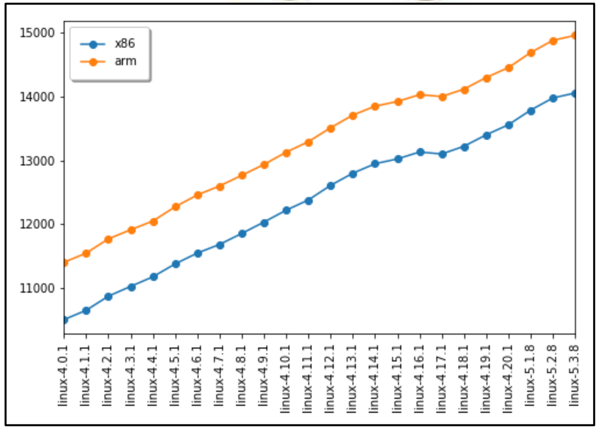
```

General problem:

Taming the configuration space



15,000+ options



TRISTATE	61.63
BOOL	36.40
INT	1.54
STRING	0.29
HEX	0.14

Linux 5.2.8, arm
(% of types' options)

3^{9000}

2^{6000}

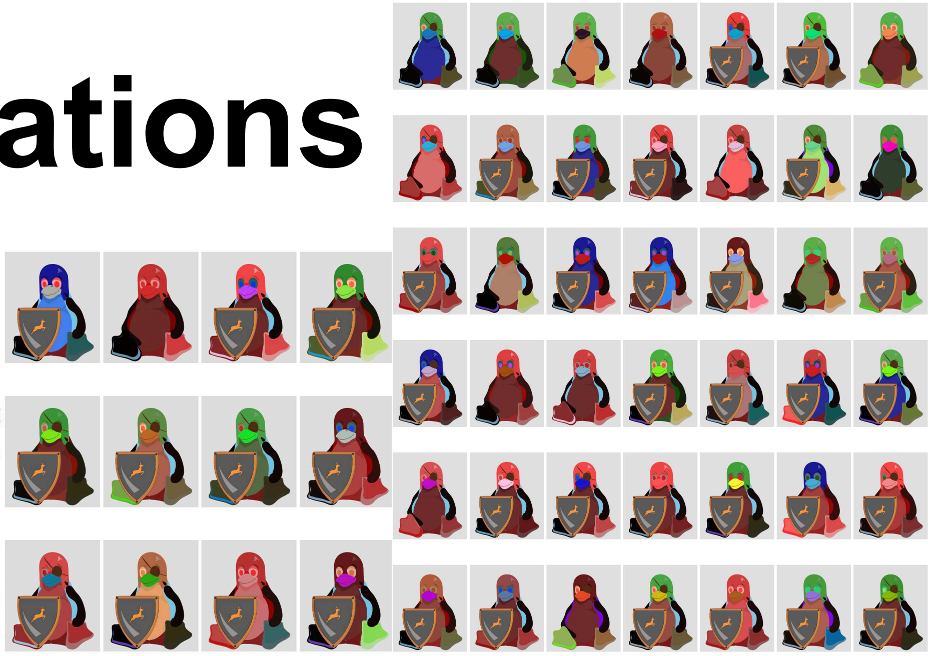
$\approx 10^{6000}$ configurations

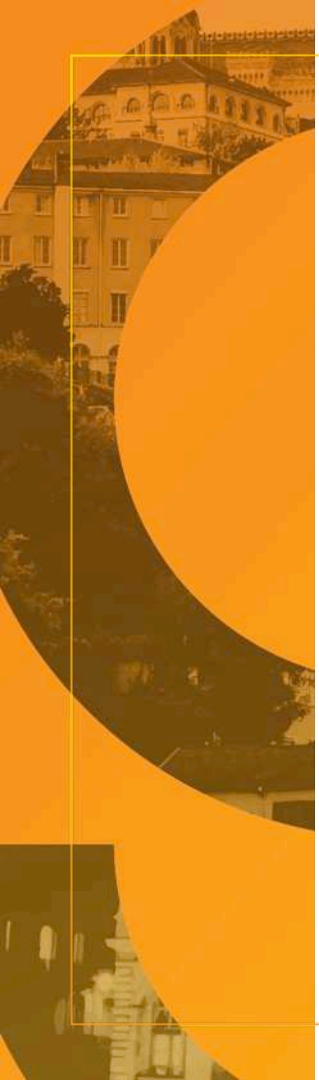
(without constraints)

Linux Kernel

$\approx 10^{6000}$

configurations





Linux Kernel

≈10^{6000} configurations

≈10^{80} is the estimated number of atoms in the universe

≈10^{40} is the estimated number of possible chess positions

Linux vs AlphaZero

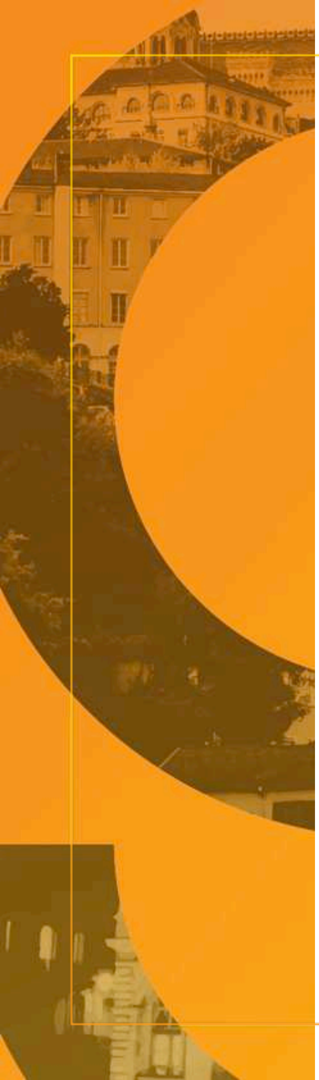
Building a kernel configuration takes **10 minutes on average** on a recent machine

Trial and error is **cheap** for Chess/Go, you can experience winning/losing billions of time

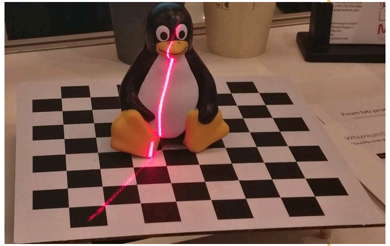
AlphaZero vs Linux

In Chess/Go, you can fully observe the outcome, without noise and with a **perfect simulator**

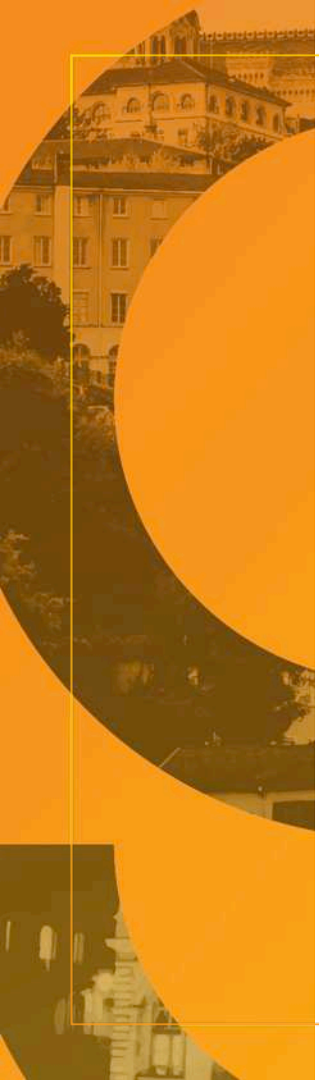
Think about **technically measuring the boot time** of a kernel out of a configuration



Is taming the Linux kernel configuration space a harder problem than resolving Chess?

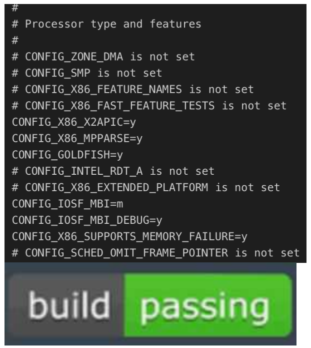


# configurations	$\approx 10^{6000}$	$\approx 10^{40}$
exploration	costly and hard to engineer	cheap with a perfect simulator



You cannot build ≈10^{6000} configurations.

TUXML: predicting out of a (small) <u>sample</u> of configurations' kernels



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CONFIG_IOSF_MBI=m
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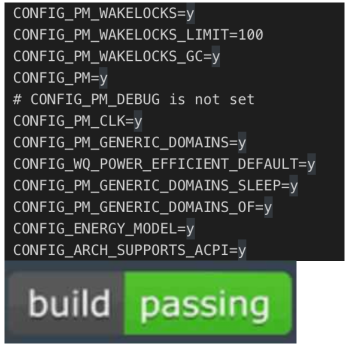
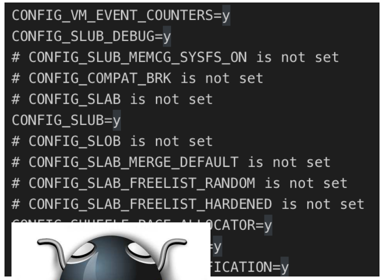
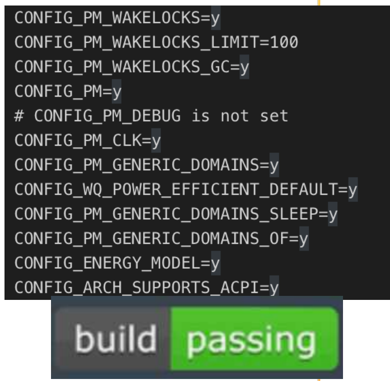
```



```
CONFIG_PM_WAKELOCKS=y
CONFIG_PM_WAKELOCKS_LIMIT=100
CONFIG_PM_WAKELOCKS_GC=y
CONFIG_PM=y
# CONFIG_PM_DEBUG is not set
CONFIG_PM_CLK=y
CONFIG_PM_GENERIC_DOMAINS=y
CONFIG_WQ_POWER_EFFICIENT_DEFAULT=y
CONFIG_PM_GENERIC_DOMAINS_SLEEP=y
CONFIG_PM_GENERIC_DOMAINS_OF=y
CONFIG_ENERGY_MODEL=y
CONFIG_ARCH_SUPPORTS_ACPI=y
```



```
CONFIG_VM_EVENT_COUNTERS=y
CONFIG_SLUB_DEBUG=y
# CONFIG_SLUB_MEMCG_SYSFS_ON is not set
# CONFIG_COMPAT_BRK is not set
# CONFIG_SLAB is not set
CONFIG_SLUB=y
# CONFIG_SLOB is not set
# CONFIG_SLAB_MERGE_DEFAULT is not set
# CONFIG_SLAB_FREELIST_RANDOM is not set
# CONFIG_SLAB_FREELIST_HARDENED is not set
CONFIG_SHUFFLE_PAGE_ALLOCATOR=y
                      y
                      FICATION=y
```



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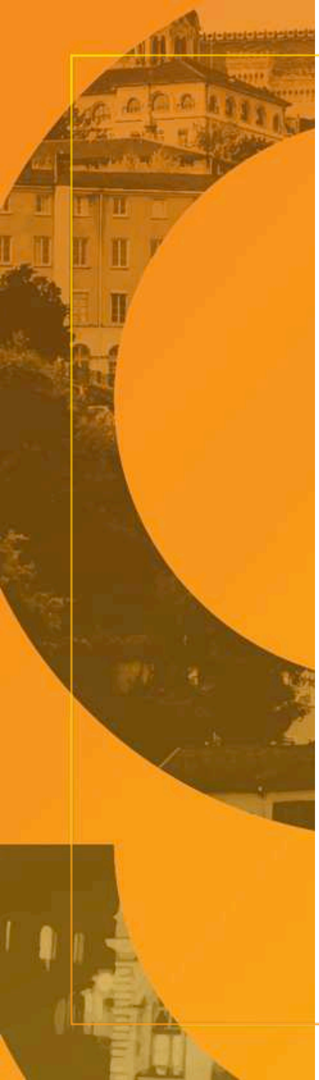
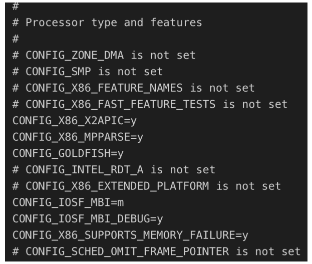
CONFIG_PM_GENERIC_DOMAINS_OF=y
CONFIG_ENERGY_MODEL=y
CONFIG_ARCH_SUPPORTS_ACPI=y
```

Classification problem:
predict the class (BUILD/FAILURE)
out of options values



You cannot build ≈10^{6000} configurations.

TUXML: predicting out of a (small) sample of configurations' kernels



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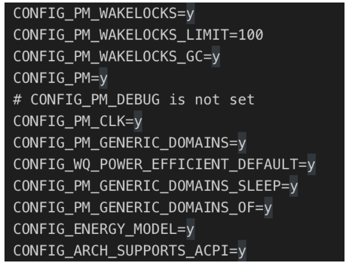
# CONFIG_SCHED_OMIT_FRAME_POINTER is not set
```

7.1Mb



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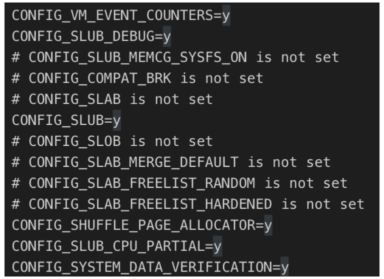
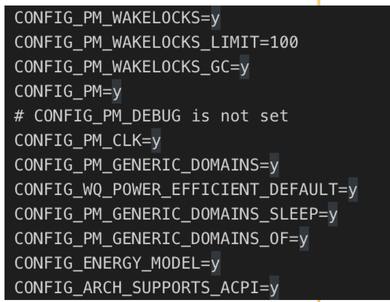
CONFIG_WQ_POWER_EFFICIENT_DEFAULT=y
CONFIG_PM_GENERIC_DOMAINS_SLEEP=y
CONFIG_PM_GENERIC_DOMAINS_OF=y
CONFIG_ENERGY_MODEL=y
CONFIG_ARCH_SUPPORTS_ACPI=y
```

176.8Mb



```
CONFIG_VM_EVENT_COUNTERS=y
CONFIG_SLUB_DEBUG=y
# CONFIG_SLUB_MEMCG_SYSFS_ON is not set
# CONFIG_COMPAT_BRK is not set
# CONFIG_SLAB is not set
CONFIG_SLUB=y
# CONFIG_SLOB is not set
# CONFIG_SLAB_MERGE_DEFAULT is not set
# CONFIG_SLAB_FREELIST_RANDOM is not set
# CONFIG_SLAB_FREELIST_HARDENED is not set
CONFIG_SHUFFLE_PAGE_ALLOCATOR=y
CONFIG_SLUB_CPU_PARTIAL=y
CONFIG_SYSTEM_DATA_VERIFICATION=y
```

16.1Mb



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CONFIG_PM_WAKELOCKS_GC=y
CONFIG_PM=y
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CONFIG_PM_GENERIC_DOMAINS=y
CONFIG_WQ_POWER_EFFICIENT_DEFAULT=y
CONFIG_PM_GENERIC_DOMAINS_SLEEP=y
CONFIG_PM_GENERIC_DOMAINS_OF=y
CONFIG_ENERGY_MODEL=y
CONFIG_ARCH_SUPPORTS_ACPI=y
```

102.3Mb

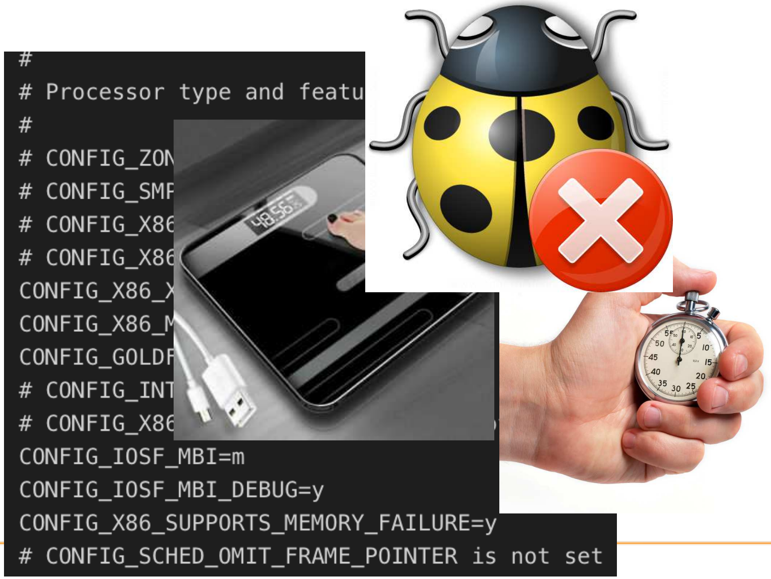
Regression problem:
predict a quantitative value (eg size)
out of options values

You cannot build ≈10^{6000} configurations.

TUXML: predicting out of a (small) sample of configurations' kernels

```
#
# Processor type and featu
#
# CONFIG_ZON
# CONFIG_SMP
# CONFIG_X86
# CONFIG_X86
CONFIG_X86_X
CONFIG_X86_M
CONFIG_GOLDF
# CONFIG_INT
# CONFIG_X86
CONFIG_IOSF_MBI=m
CONFIG_IOSF_MBI_DEBUG=y
CONFIG_X86_SUPPORTS_MEMORY_FAILURE=y
# CONFIG_SCHED_OMIT_FRAME_POINTER is not set
```

You cannot build ≈10^{6000} configurations. Is machine learning effective for such very large configurable systems?

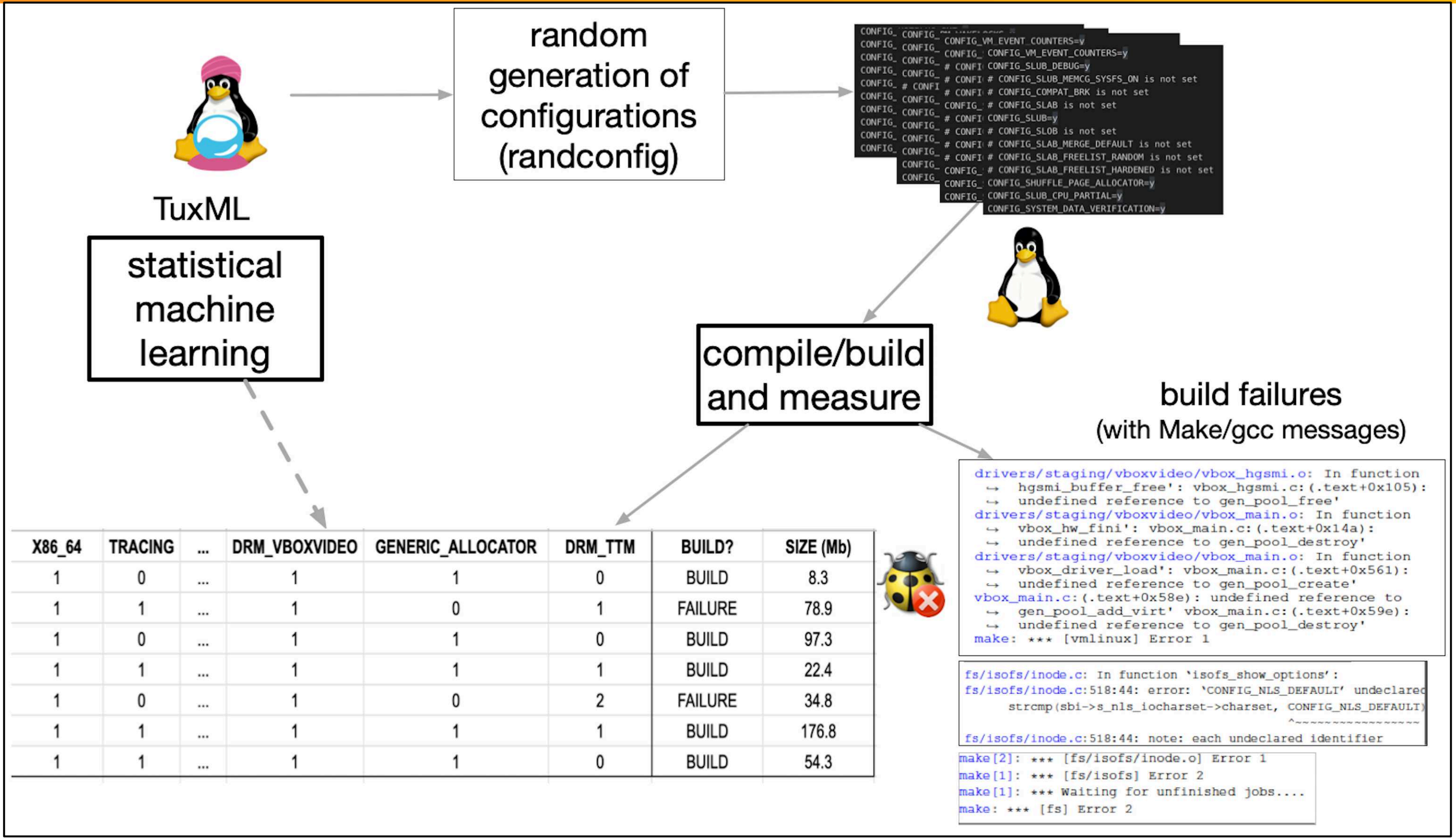


```
#
# Processor type and featu
#
# CONFIG_ZON
# CONFIG_SMF
# CONFIG_X86
# CONFIG_X86
CONFIG_X86_X
CONFIG_X86_M
CONFIG_GOLDF
# CONFIG_INT
# CONFIG_X86
CONFIG_IOSF_MBI=m
CONFIG_IOSF_MBI_DEBUG=y
CONFIG_X86_SUPPORTS_MEMORY_FAILURE=y
# CONFIG_SCHED_OMIT_FRAME_POINTER is not set
```

Answers in the rest of the talk

- Sampling and Learning with TUXML
- Results over 150K+ configurations
  - build failure understanding and prevention
  - kernel size prediction
- Challenges
  - “smart” build infrastructure
  - with devs/contributors in the loop

TUXML: Sampling, Measuring, Learning


random generation of configurations (randconfig)
TuxML
statistical machine learning
compile/build and measure
build failures
(with Make/gcc messages)

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CONFIG_SYSTEM_DATA_VERIFICATION=y
```

X86_64	TRACING	...	DRM_VBOXVIDEO	GENERIC_ALLOCATOR	DRM_TTM	BUILD?	SIZE (Mb)
1	0	...	1	1	0	BUILD	8.3
1	1	...	1	0	1	FAILURE	78.9
1	0	...	1	1	0	BUILD	97.3
1	1	...	1	1	1	BUILD	22.4
1	0	...	1	0	2	FAILURE	34.8
1	1	...	1	1	1	BUILD	176.8
1	1	...	1	1	0	BUILD	54.3

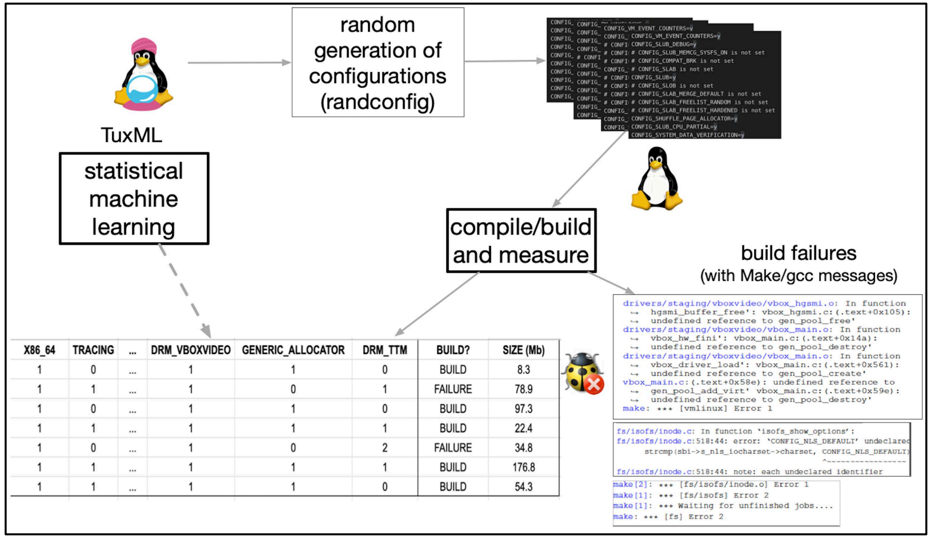
```
drivers/staging/vboxvideo/vbox_hgsmi.o: In function
 ↪  hgsmi_buffer_free': vbox_hgsmi.c:(.text+0x105):
 ↪  undefined reference to gen_pool_free'
drivers/staging/vboxvideo/vbox_main.o: In function
 ↪  vbox_hw_fini': vbox_main.c:(.text+0x14a):
 ↪  undefined reference to gen_pool_destroy'
drivers/staging/vboxvideo/vbox_main.o: In function
 ↪  vbox_driver_load': vbox_main.c:(.text+0x561):
 ↪  undefined reference to gen_pool_create'
vbox_main.c:(.text+0x58e): undefined reference to
 ↪  gen_pool_add_virt' vbox_main.c:(.text+0x59e):
 ↪  undefined reference to gen_pool_destroy'
make: *** [vmlinux] Error 1
```

```
fs/isofs/inode.c: In function 'isofs_show_options':
fs/isofs/inode.c:518:44: error: 'CONFIG_NLS_DEFAULT' undeclared
     strcmp(sbi->s_nls_iocharset->charset, CONFIG_NLS_DEFAULT)
                                           ^~~~~~~~~~~~~~~~~~
fs/isofs/inode.c:518:44: note: each undeclared identifier
```

```
make[2]: *** [fs/isofs/inode.o] Error 1
make[1]: *** [fs/isofs] Error 2
make[1]: *** Waiting for unfinished jobs....
make: *** [fs] Error 2
```

TUXML: Sampling, Measuring, Learning

https://github.com/TuxML/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random generation of configurations (randconfig)
statistical machine learning
compile/build and measure
build failures
(with Make/gcc messages)

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drivers/staging/vboxvideo/vbox_main.o: In function
 ↪  vbox_driver_load': vbox_main.c:(.text+0x561):
 ↪  undefined reference to gen_pool_create'
vbox_main.c:(.text+0x58e): undefined reference to
 ↪  gen_pool_add_virt' vbox_main.c:(.text+0x59e):
 ↪  undefined reference to gen_pool_destroy'
make: *** [vmlinux] Error 1
```

```
fs/isofs/inode.c: In function 'isofs_show_options':
fs/isofs/inode.c:518:44: error: 'CONFIG_NLS_DEFAULT' undeclared
     strcmp(sbi->s_nls_iocharset->charset, CONFIG_NLS_DEFAULT)
                                           ^~~~~~~~~~~~~~~~~~
fs/isofs/inode.c:518:44: note: each undeclared identifier
```

```
make[2]: *** [fs/isofs/inode.o] Error 1
make[1]: *** [fs/isofs] Error 2
make[1]: *** Waiting for unfinished jobs....
make: *** [fs] Error 2
```

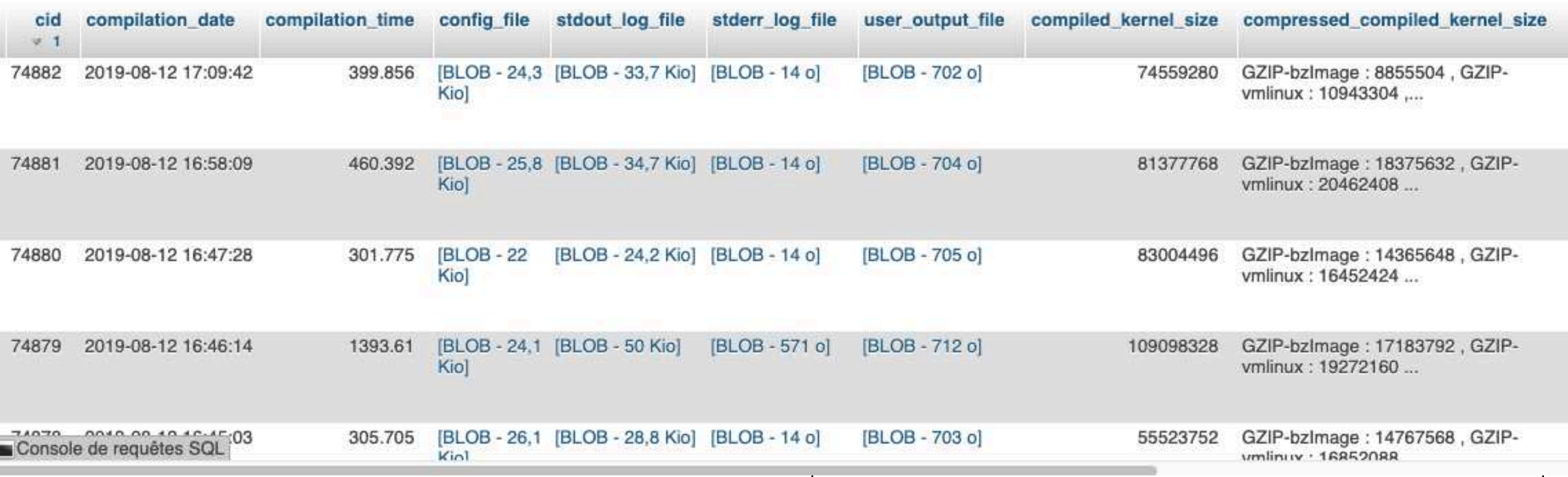
Docker for a reproducible environment with tools/packages needed and **Python** procedures inside

Easy to launch campaign:
”python kernel_generator.py 10”

builds/measures
10 random configurations
(information sent to a database)

TUXML: Sampling, Measuring, Learning

https://github.com/TuxML/

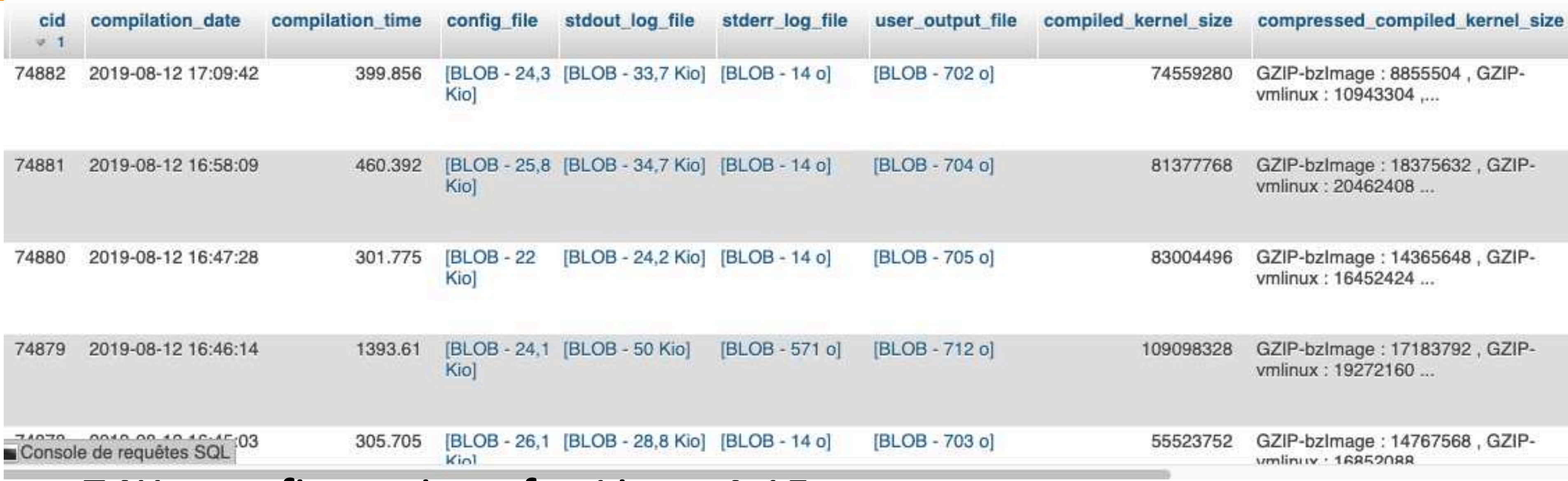


cid ▾ 1	compilation_date	compilation_time	config_file	stdout_log_file	stderr_log_file	user_output_file	compiled_kernel_size	compressed_compiled_kernel_size
74882	2019-08-12 17:09:42	399.856	[BLOB - 24,3 Kio]	[BLOB - 33,7 Kio]	[BLOB - 14 o]	[BLOB - 702 o]	74559280	GZIP-bzImage : 8855504 , GZIP-vmlinux : 10943304 ,...
74881	2019-08-12 16:58:09	460.392	[BLOB - 25,8 Kio]	[BLOB - 34,7 Kio]	[BLOB - 14 o]	[BLOB - 704 o]	81377768	GZIP-bzImage : 18375632 , GZIP-vmlinux : 20462408 ...
74880	2019-08-12 16:47:28	301.775	[BLOB - 22 Kio]	[BLOB - 24,2 Kio]	[BLOB - 14 o]	[BLOB - 705 o]	83004496	GZIP-bzImage : 14365648 , GZIP-vmlinux : 16452424 ...
74879	2019-08-12 16:46:14	1393.61	[BLOB - 24,1 Kio]	[BLOB - 50 Kio]	[BLOB - 571 o]	[BLOB - 712 o]	109098328	GZIP-bzImage : 17183792 , GZIP-vmlinux : 19272160 ...
74878	2019-08-12 16:45:03	305.705	[BLOB - 26,1 Kio]	[BLOB - 28,8 Kio]	[BLOB - 14 o]	[BLOB - 703 o]	55523752	GZIP-bzImage : 14767568 , GZIP-vmlinux : 16852088

Console de requêtes SQL

(information sent to a database)

Data: version 4.13.3 and 4.15 (x86_64)



cid ▾ 1	compilation_date	compilation_time	config_file	stdout_log_file	stderr_log_file	user_output_file	compiled_kernel_size	compressed_compiled_kernel_size
74882	2019-08-12 17:09:42	399.856	[BLOB - 24,3 Kio]	[BLOB - 33,7 Kio]	[BLOB - 14 o]	[BLOB - 702 o]	74559280	GZIP-bzImage : 8855504 , GZIP-vmlinux : 10943304 ,...
74881	2019-08-12 16:58:09	460.392	[BLOB - 25,8 Kio]	[BLOB - 34,7 Kio]	[BLOB - 14 o]	[BLOB - 704 o]	81377768	GZIP-bzImage : 18375632 , GZIP-vmlinux : 20462408 ...
74880	2019-08-12 16:47:28	301.775	[BLOB - 22 Kio]	[BLOB - 24,2 Kio]	[BLOB - 14 o]	[BLOB - 705 o]	83004496	GZIP-bzImage : 14365648 , GZIP-vmlinux : 16452424 ...
74879	2019-08-12 16:46:14	1393.61	[BLOB - 24,1 Kio]	[BLOB - 50 Kio]	[BLOB - 571 o]	[BLOB - 712 o]	109098328	GZIP-bzImage : 17183792 , GZIP-vmlinux : 19272160 ...
74878	2019-08-12 16:45:03	305.705	[BLOB - 26,1 Kio]	[BLOB - 28,8 Kio]	[BLOB - 14 o]	[BLOB - 703 o]	55523752	GZIP-bzImage : 14767568 , GZIP-vmlinux : 16852088

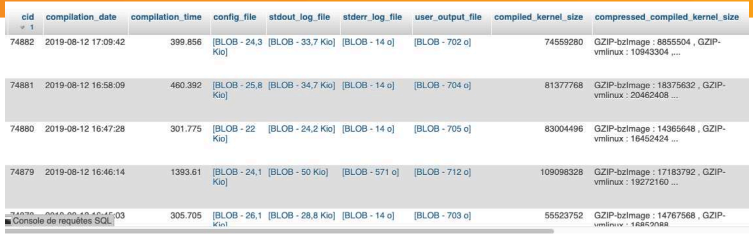
Console de requêtes SQL

74K+ configurations for Linux 4.15

95K+ configurations for Linux 4.13.3

(and 15K hours of computation on a grid computing)

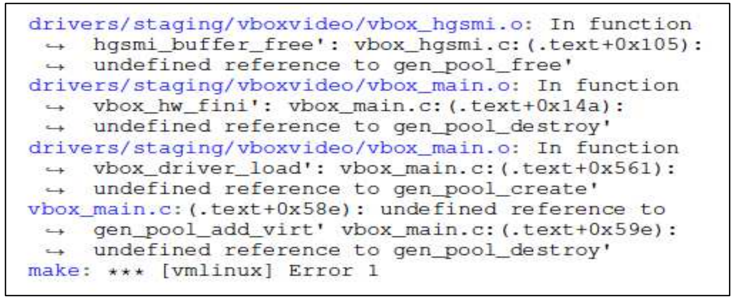
Application 1: “Smart” build infrastructure



cid	compilation_date	compilation_time	config_file	stdout_log_file	stderr_log_file	user_output_file	compiled_kernel_size	compressed_compiled_kernel_size
74882	2019-08-12 17:09:42	399.856	[BLOB - 24,3 Kio]	[BLOB - 33,7 Kio]	[BLOB - 14 o]	[BLOB - 702 o]	74559280	GZIP-bzImage : 8855504 , GZIP-vmlinux : 10943304 ,...
74881	2019-08-12 16:58:09	460.392	[BLOB - 25,8 Kio]	[BLOB - 34,7 Kio]	[BLOB - 14 o]	[BLOB - 704 o]	81377768	GZIP-bzImage : 18375632 , GZIP-vmlinux : 20462408 ...
74880	2019-08-12 16:47:28	301.775	[BLOB - 22 Kio]	[BLOB - 24,2 Kio]	[BLOB - 14 o]	[BLOB - 705 o]	83004496	GZIP-bzImage : 14365648 , GZIP-vmlinux : 16452424 ...
74879	2019-08-12 16:46:14	1393.61	[BLOB - 24,1 Kio]	[BLOB - 50 Kio]	[BLOB - 571 o]	[BLOB - 712 o]	109098328	GZIP-bzImage : 17183792 , GZIP-vmlinux : 19272160 ...
74878	2019-08-12 16:45:03	305.705	[BLOB - 26,1 Kio]	[BLOB - 28,8 Kio]	[BLOB - 14 o]	[BLOB - 703 o]	55523752	GZIP-bzImage : 14767568 , GZIP-vmlinux : 16852088

Console de requêtes SQL

results for 4.13.3 only

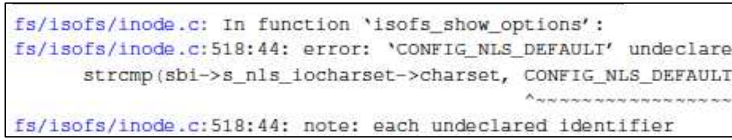


```
drivers/staging/vboxvideo/vbox_hgsmi.o: In function
 ↪   hgsmi_buffer_free': vbox_hgsmi.c:(.text+0x105):
 ↪   undefined reference to gen_pool_free'
drivers/staging/vboxvideo/vbox_main.o: In function
 ↪   vbox_hw_fini': vbox_main.c:(.text+0x14a):
 ↪   undefined reference to gen_pool_destroy'
drivers/staging/vboxvideo/vbox_main.o: In function
 ↪   vbox_driver_load': vbox_main.c:(.text+0x561):
 ↪   undefined reference to gen_pool_create'
vbox_main.c:(.text+0x58e): undefined reference to
 ↪   gen_pool_add_virt' vbox_main.c:(.text+0x59e):
 ↪   undefined reference to gen_pool_destroy'
make: *** [vmlinux] Error 1
```

95,854 configurations

3,164 configuration failures

5.83% of build lead to failures



```
fs/isofs/inode.c: In function ‘isofs_show_options’:
fs/isofs/inode.c:518:44: error: ‘CONFIG_NLS_DEFAULT’ undeclare
      strcmp(sbi->s_nls_iocharset->charset, CONFIG_NLS_DEFAULT
                                            ^~~~~~~~~~~~~~~~~~

fs/isofs/inode.c:518:44: note: each undeclared identifier
```

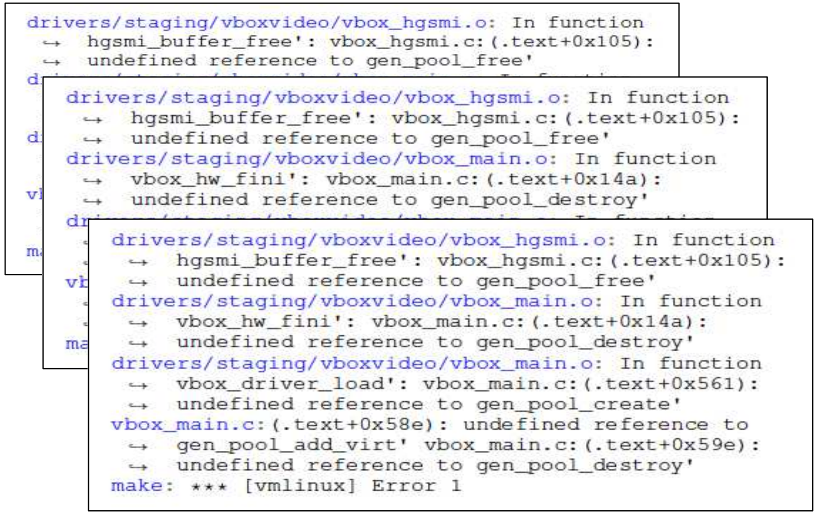
Should we send 3,164 bug reports?

Application 1: “Smart” build infrastructure

One configuration **bug**
can lead to
<u>many</u> configuration
failures

DRM_VBOXVIDEO &
GENERIC_ALLOCATOR

367 failures like this



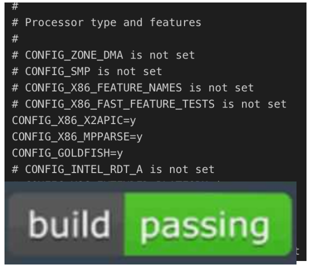
```
drivers/staging/vboxvideo/vbox_hgsmi.o: In function
 ↪  hgsmi_buffer_free': vbox_hgsmi.c:(.text+0x105):
 ↪  undefined reference to gen_pool_free'
```

```
drivers/staging/vboxvideo/vbox_hgsmi.o: In function
 ↪  hgsmi_buffer_free': vbox_hgsmi.c:(.text+0x105):
 ↪  undefined reference to gen_pool_free'
drivers/staging/vboxvideo/vbox_main.o: In function
 ↪  vbox_hw_fini': vbox_main.c:(.text+0x14a):
 ↪  undefined reference to gen_pool_destroy'
```

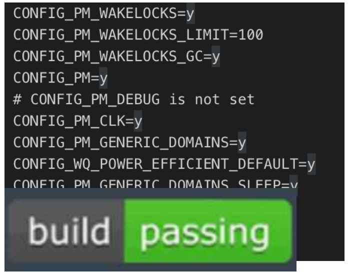
```
drivers/staging/vboxvideo/vbox_hgsmi.o: In function
 ↪  hgsmi_buffer_free': vbox_hgsmi.c:(.text+0x105):
 ↪  undefined reference to gen_pool_free'
drivers/staging/vboxvideo/vbox_main.o: In function
 ↪  vbox_hw_fini': vbox_main.c:(.text+0x14a):
 ↪  undefined reference to gen_pool_destroy'
drivers/staging/vboxvideo/vbox_main.o: In function
 ↪  vbox_driver_load': vbox_main.c:(.text+0x561):
 ↪  undefined reference to gen_pool_create'
vbox_main.c:(.text+0x58e): undefined reference to
 ↪  gen_pool_add_virt' vbox_main.c:(.text+0x59e):
 ↪  undefined reference to gen_pool_destroy'
make: *** [vmlinux] Error 1
```

Statistical learning can **automatically** pinpoint what combinations of options lead to a failure

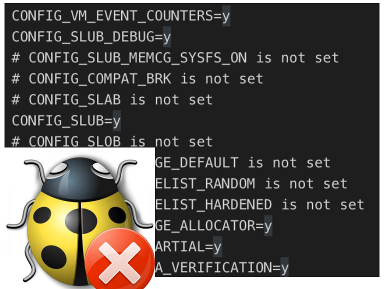
Classification problem: predict the class (BUILD/ FAILURE) out of options values



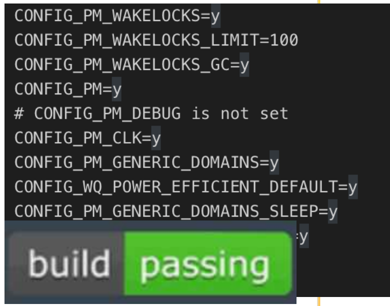
```
#
# Processor type and features
#
# CONFIG_ZONE_DMA is not set
# CONFIG_SMP is not set
# CONFIG_X86_FEATURE_NAMES is not set
# CONFIG_X86_FAST_FEATURE_TESTS is not set
CONFIG_X86_X2APIC=y
CONFIG_X86_MPPARSE=y
CONFIG_GOLDFISH=y
# CONFIG_INTEL_RDT_A is not set
```



```
CONFIG_PM_WAKELOCKS=y
CONFIG_PM_WAKELOCKS_LIMIT=100
CONFIG_PM_WAKELOCKS_GC=y
CONFIG_PM=y
# CONFIG_PM_DEBUG is not set
CONFIG_PM_CLK=y
CONFIG_PM_GENERIC_DOMAINS=y
CONFIG_WQ_POWER_EFFICIENT_DEFAULT=y
CONFIG_PM_GENERIC_DOMAINS_SLEEP=y
```



```
CONFIG_VM_EVENT_COUNTERS=y
CONFIG_SLUB_DEBUG=y
# CONFIG_SLUB_MEMCG_SYSFS_ON is not set
# CONFIG_COMPAT_BRK is not set
# CONFIG_SLAB is not set
CONFIG_SLUB=y
# CONFIG_SLOB is not set
GE_DEFAULT is not set
ELIST_RANDOM is not set
ELIST_HARDENED is not set
GE_ALLOCATOR=y
ARTIAL=y
A_VERIFICATION=y
```



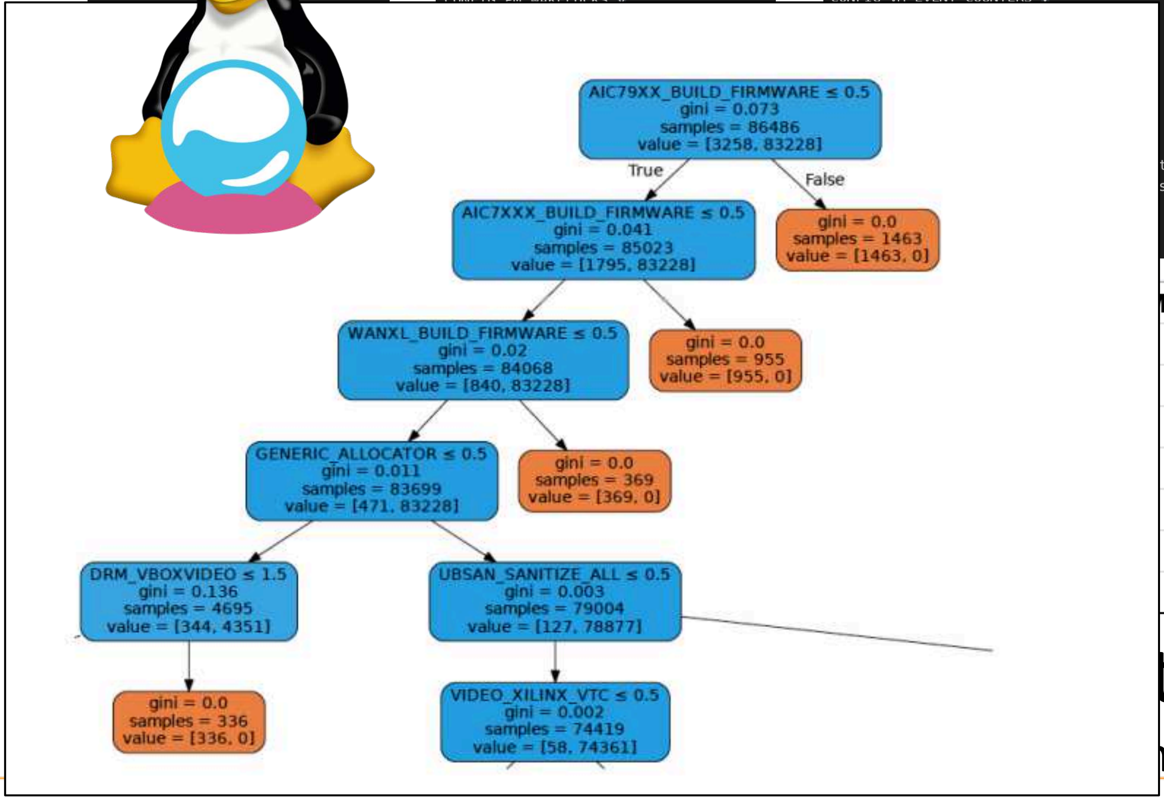
```
CONFIG_PM_WAKELOCKS=y
CONFIG_PM_WAKELOCKS_LIMIT=100
CONFIG_PM_WAKELOCKS_GC=y
CONFIG_PM=y
# CONFIG_PM_DEBUG is not set
CONFIG_PM_CLK=y
CONFIG_PM_GENERIC_DOMAINS=y
CONFIG_WQ_POWER_EFFICIENT_DEFAULT=y
CONFIG_PM_GENERIC_DOMAINS_SLEEP=y
                                  :y
```

X86_64	TRACING	...	DRM_VBOXVIDEO	GENERIC_ALLOCATOR	DRM_TTM	BUILD?	SIZE (Mb)
1	0	...	1	1	0	BUILD	8.3
1	1	...	1	0	1	FAILURE	78.9
1	0	...	1	1	0	BUILD	97.3
1	1	...	1	1	1	BUILD	22.4
1	0	...	1	0	2	FAILURE	34.8
1	1	...	1	1	1	BUILD	176.8
1	1	...	1	1	0	BUILD	54.3

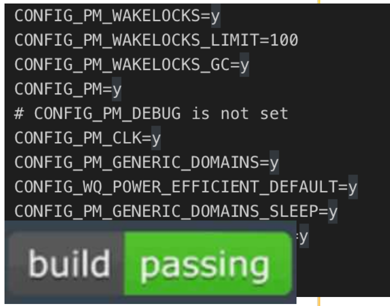
Do you recognize a pattern?

(matrix is 95K rows and 12K columns)

Classification tree



```
#
CONFIG_PM_WAKELOCKS=y
CONFIG_VM_EVENT_COUNTERS=y
t
set
```



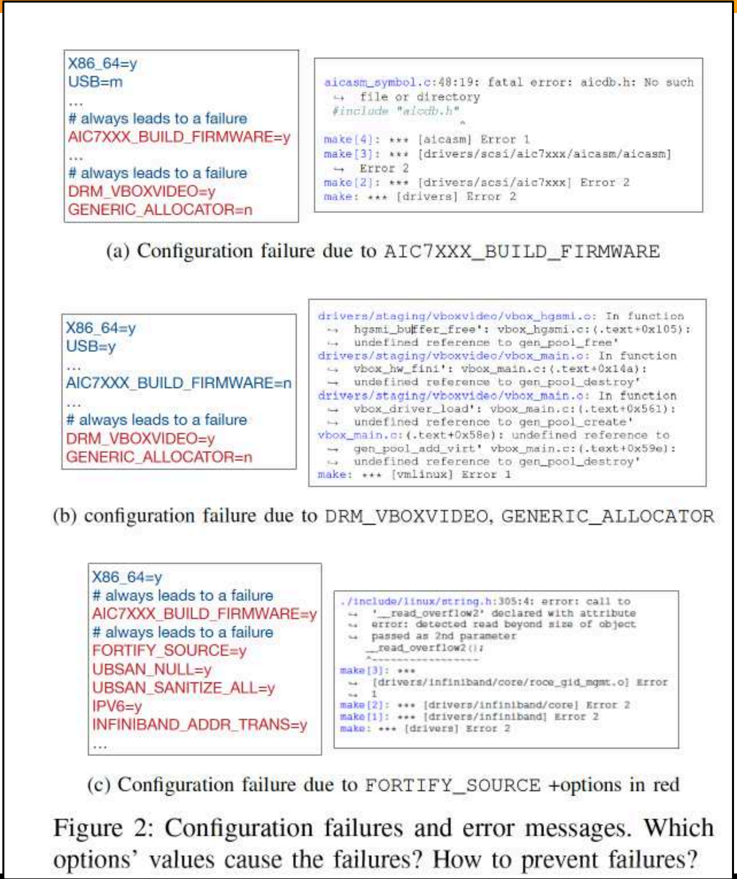
```
CONFIG_PM_WAKELOCKS=y
CONFIG_PM_WAKELOCKS_LIMIT=100
CONFIG_PM_WAKELOCKS_GC=y
CONFIG_PM=y
# CONFIG_PM_DEBUG is not set
CONFIG_PM_CLK=y
CONFIG_PM_GENERIC_DOMAINS=y
CONFIG_WQ_POWER_EFFICIENT_DEFAULT=y
CONFIG_PM_GENERIC_DOMAINS_SLEEP=y
:y
```

BUILD?	SIZE (Mb)
BUILD	8.3
FAILURE	78.9
BUILD	97.3
BUILD	22.4
FAILURE	34.8
BUILD	176.8
BUILD	54.3

tern?

mns)

Application 1: “Smart” build infrastructure



```
X86_64=y
USB=m
...
# always leads to a failure
AIC7XXX_BUILD_FIRMWARE=y
...
# always leads to a failure
DRM_VBOXVIDEO=y
GENERIC_ALLOCATOR=n
```

```
aicasm_symbol.c:48:19: fatal error: aicdb.h: No such
 ↪  file or directory
 #include "aicdb.h"
                   ^
make[4]: *** [aicasm] Error 1
make[3]: *** [drivers/scsi/aic7xxx/aicasm/aicasm]
 ↪  Error 2
make[2]: *** [drivers/scsi/aic7xxx] Error 2
make: *** [drivers] Error 2
```

(a) Configuration failure due to AIC7XXX_BUILD_FIRMWARE

```
X86_64=y
USB=y
...
AIC7XXX_BUILD_FIRMWARE=n
...
# always leads to a failure
DRM_VBOXVIDEO=y
GENERIC_ALLOCATOR=n
```

```
drivers/staging/vboxvideo/vbox_hgsmi.o: In function
 ↪  hgsmi_buffer_free': vbox_hgsmi.c:(.text+0x105):
 ↪  undefined reference to gen_pool_free'
drivers/staging/vboxvideo/vbox_main.o: In function
 ↪  vbox_hw_fini': vbox_main.c:(.text+0x14a):
 ↪  undefined reference to gen_pool_destroy'
drivers/staging/vboxvideo/vbox_main.o: In function
 ↪  vbox_driver_load': vbox_main.c:(.text+0x561):
 ↪  undefined reference to gen_pool_create'
vbox_main.o:(.text+0x58e): undefined reference to
 ↪  gen_pool_add_virt' vbox_main.c:(.text+0x59e):
 ↪  undefined reference to gen_pool_destroy'
make: *** [vmlinux] Error 1
```

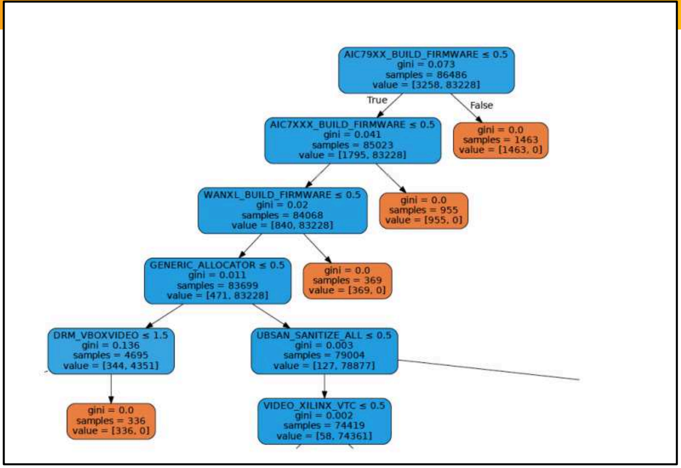
(b) configuration failure due to DRM_VBOXVIDEO, GENERIC_ALLOCATOR

```
X86_64=y
# always leads to a failure
AIC7XXX_BUILD_FIRMWARE=y
# always leads to a failure
FORTIFY_SOURCE=y
UBSAN_NULL=y
UBSAN_SANITIZE_ALL=y
IPV6=y
INFINIBAND_ADDR_TRANS=y
...
```

```
./include/linux/string.h:305:4: error: call to
 ↪  '__read_overflow2' declared with attribute
 ↪  error: detected read beyond size of object
 ↪  passed as 2nd parameter
    __read_overflow2();
    ^~~~~~~~~~~~~~~~~~~
make[3]: ***
 ↪  [drivers/infiniband/core/roce_gid_mgmt.o] Error
 ↪  1
make[2]: *** [drivers/infiniband/core] Error 2
make[1]: *** [drivers/infiniband] Error 2
make: *** [drivers] Error 2
```

(c) Configuration failure due to FORTIFY_SOURCE +options in red

Figure 2: Configuration failures and error messages. Which options’ values cause the failures? How to prevent failures?



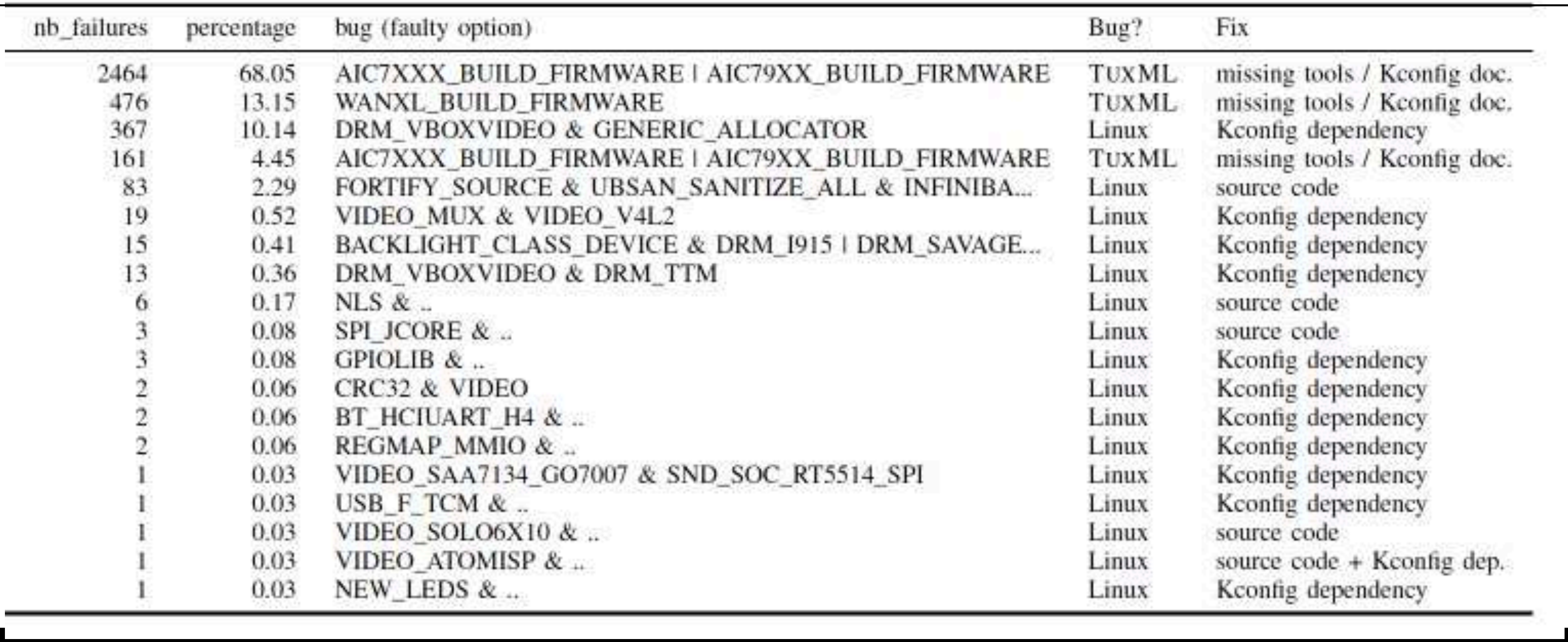
AIC79XX_BUILD_FIRMWARE ≤ 0.5 gini = 0.073 samples = 86486 value = [3258, 83228]
True
False
AIC7XXX_BUILD_FIRMWARE ≤ 0.5 gini = 0.041 samples = 85023 value = [1795, 83228]
gini = 0.0 samples = 1463 value = [1463, 0]
WANXL_BUILD_FIRMWARE ≤ 0.5 gini = 0.02 samples = 84068 value = [840, 83228]
gini = 0.0 samples = 955 value = [955, 0]
GENERIC_ALLOCATOR ≤ 0.5 gini = 0.011 samples = 83699 value = [471, 83228]
gini = 0.0 samples = 369 value = [369, 0]
DRM_VBOXVIDEO ≤ 1.5 gini = 0.136 samples = 4695 value = [344, 4351]
UBSAN_SANITIZE_ALL ≤ 0.5 gini = 0.003 samples = 79004 value = [127, 78877]
gini = 0.0 samples = 336 value = [336, 0]
VIDEO_XILINX_VTC ≤ 0.5 gini = 0.002 samples = 74419 value = [58, 74361]

Some config. bugs can **mask/ dominate** other config. bugs!

Solution (see paper): statistical **learning** combined with **clustering** of error messages (multi-class classification)

Application 1: “Smart” build infrastructure

5.83% of build failures can be explained by **16** config. bugs of Linux and **3** config. bugs of TUXML



nb_failures	percentage	bug (faulty option)	Bug?	Fix
2464	68.05	AIC7XXX_BUILD_FIRMWARE | AIC79XX_BUILD_FIRMWARE	TUXML	missing tools / Kconfig doc.
476	13.15	WANXL_BUILD_FIRMWARE	TUXML	missing tools / Kconfig doc.
367	10.14	DRM_VBOXVIDEO & GENERIC_ALLOCATOR	Linux	Kconfig dependency
161	4.45	AIC7XXX_BUILD_FIRMWARE | AIC79XX_BUILD_FIRMWARE	TUXML	missing tools / Kconfig doc.
83	2.29	FORTIFY_SOURCE & UBSAN_SANITIZE_ALL & INFINIBA...	Linux	source code
19	0.52	VIDEO_MUX & VIDEO_V4L2	Linux	Kconfig dependency
15	0.41	BACKLIGHT_CLASS_DEVICE & DRM_I915 | DRM_SAVAGE...	Linux	Kconfig dependency
13	0.36	DRM_VBOXVIDEO & DRM_TTM	Linux	Kconfig dependency
6	0.17	NLS & ..	Linux	source code
3	0.08	SPI_JCORE & ..	Linux	source code
3	0.08	GPIOLIB & ..	Linux	Kconfig dependency
2	0.06	CRC32 & VIDEO	Linux	Kconfig dependency
2	0.06	BT_HCIUART_H4 & ..	Linux	Kconfig dependency
2	0.06	REGMAP_MMIO & ..	Linux	Kconfig dependency
1	0.03	VIDEO_SAA7134_GO7007 & SND_SOC_RT5514_SPI	Linux	Kconfig dependency
1	0.03	USB_F_TCM & ..	Linux	Kconfig dependency
1	0.03	VIDEO_SOLO6X10 & ..	Linux	source code
1	0.03	VIDEO_ATOMISP & ..	Linux	source code + Kconfig dep.
1	0.03	NEW_LEDS & ..	Linux	Kconfig dependency

Application 1: “Smart” build infrastructure

5.83% of build failures can be explained by
16 config. bugs of Linux and **3** config. bugs of TUXML

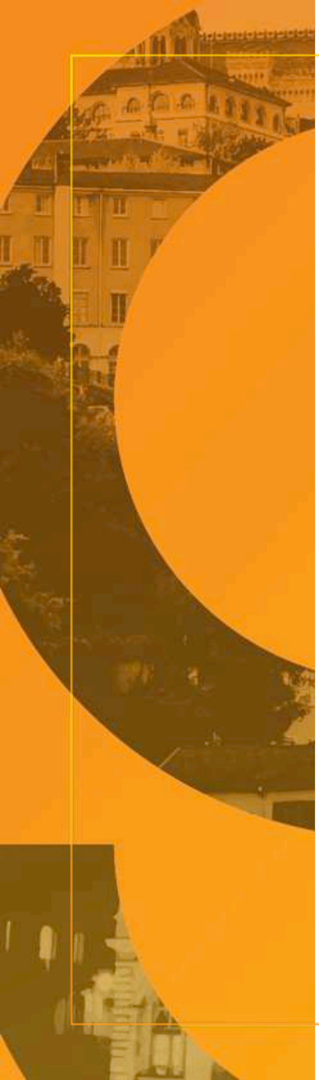
Don’t trust your configuration build infrastructure!
Prevent/Fix as early as possible configuration bugs (otherwise you won’t see other bugs!)
Bug **location/understanding**: TUXML can help to pinpoint responsible options (and avoid sending duplicate bugs)
TUXML can **prevent failures** and avoid building buggy configs (until a fix is done) with a good accuracy

Application 2: Kernel Size Prediction

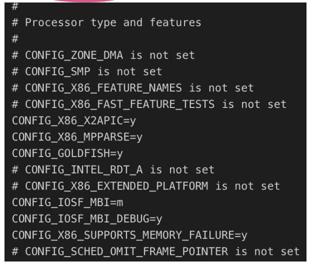
https://elinux.org/Kernel_Size_Tuning_Guide - Tim Bird (Sony)
Linux kernel tinification/tinyconfig - Josh Triplett (Intel)
Challenges of Low Spec Embedded Linux - Alexander Sack, Pantacor
Timing Boot Time Reduction Techniques - Michael Opdenacker, Bootlin
@ ELC 2019

Unfortunately, nobody knows the precise effect of (combinations of) options on size

Kconfig: (only?) 150 options are explicitly referring to size

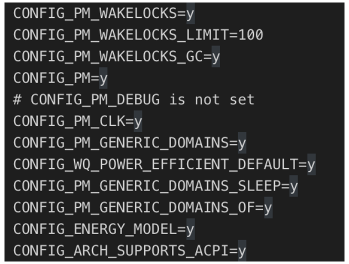


Regression problem: predict a quantitative value (eg size) out of options values



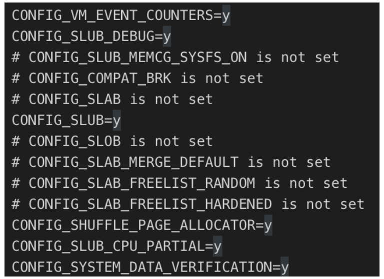
```
#
# Processor type and features
#
# CONFIG_ZONE_DMA is not set
# CONFIG_SMP is not set
# CONFIG_X86_FEATURE_NAMES is not set
# CONFIG_X86_FAST_FEATURE_TESTS is not set
CONFIG_X86_X2APIC=y
CONFIG_X86_MPPARSE=y
CONFIG_GOLDFISH=y
# CONFIG_INTEL_RDT_A is not set
# CONFIG_X86_EXTENDED_PLATFORM is not set
CONFIG_IOSF_MBI=m
CONFIG_IOSF_MBI_DEBUG=y
CONFIG_X86_SUPPORTS_MEMORY_FAILURE=y
# CONFIG_SCHED_OMIT_FRAME_POINTER is not set
```

7.1Mb



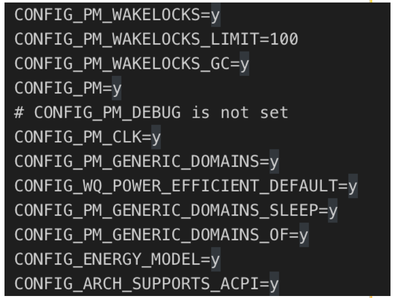
```
CONFIG_PM_WAKELOCKS=y
CONFIG_PM_WAKELOCKS_LIMIT=100
CONFIG_PM_WAKELOCKS_GC=y
CONFIG_PM=y
# CONFIG_PM_DEBUG is not set
CONFIG_PM_CLK=y
CONFIG_PM_GENERIC_DOMAINS=y
CONFIG_WQ_POWER_EFFICIENT_DEFAULT=y
CONFIG_PM_GENERIC_DOMAINS_SLEEP=y
CONFIG_PM_GENERIC_DOMAINS_OF=y
CONFIG_ENERGY_MODEL=y
CONFIG_ARCH_SUPPORTS_ACPI=y
```

176.8Mb



```
CONFIG_VM_EVENT_COUNTERS=y
CONFIG_SLUB_DEBUG=y
# CONFIG_SLUB_MEMCG_SYSFS_ON is not set
# CONFIG_COMPAT_BRK is not set
# CONFIG_SLAB is not set
CONFIG_SLUB=y
# CONFIG_SLOB is not set
# CONFIG_SLAB_MERGE_DEFAULT is not set
# CONFIG_SLAB_FREELIST_RANDOM is not set
# CONFIG_SLAB_FREELIST_HARDENED is not set
CONFIG_SHUFFLE_PAGE_ALLOCATOR=y
CONFIG_SLUB_CPU_PARTIAL=y
CONFIG_SYSTEM_DATA_VERIFICATION=y
```

16.1Mb



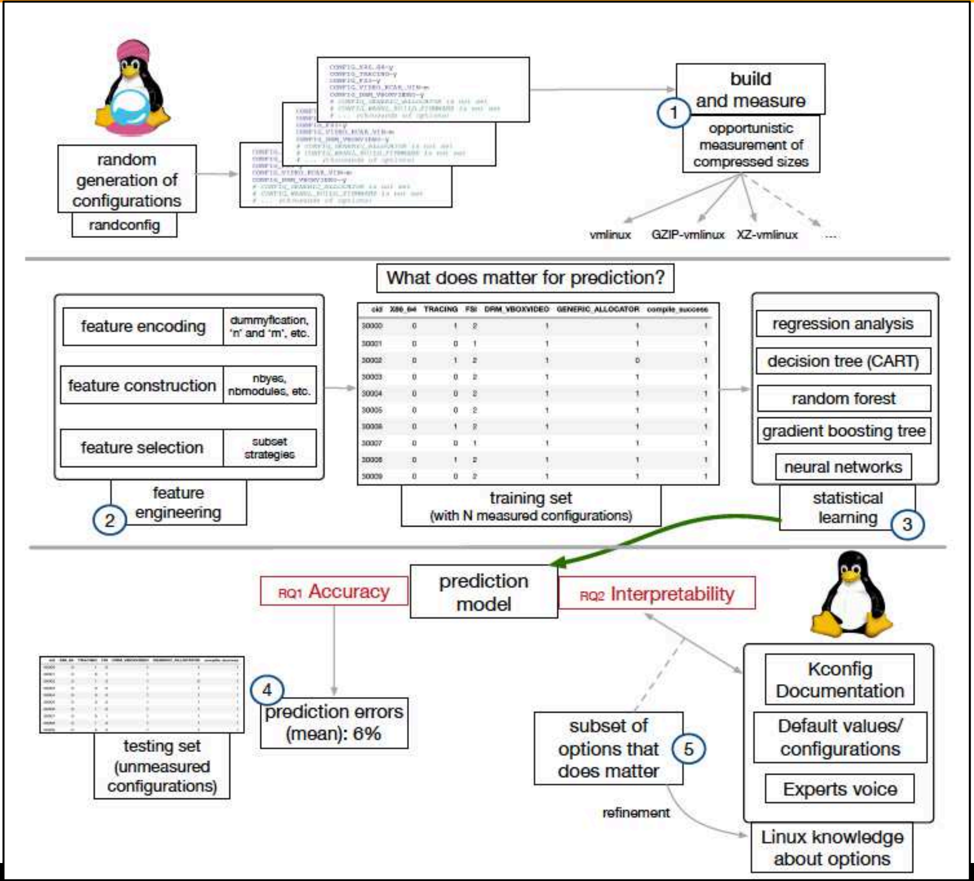
```
CONFIG_PM_WAKELOCKS=y
CONFIG_PM_WAKELOCKS_LIMIT=100
CONFIG_PM_WAKELOCKS_GC=y
CONFIG_PM=y
# CONFIG_PM_DEBUG is not set
CONFIG_PM_CLK=y
CONFIG_PM_GENERIC_DOMAINS=y
CONFIG_WQ_POWER_EFFICIENT_DEFAULT=y
CONFIG_PM_GENERIC_DOMAINS_SLEEP=y
CONFIG_PM_GENERIC_DOMAINS_OF=y
CONFIG_ENERGY_MODEL=y
CONFIG_ARCH_SUPPORTS_ACPI=y
```

102.3Mb

Smart configuration: prediction model can quantify the effect of (de-)activating options (optimizer/recommender/configurator can be built on top of it)

Documentation/default config. improvement: identification of **"influential"** options

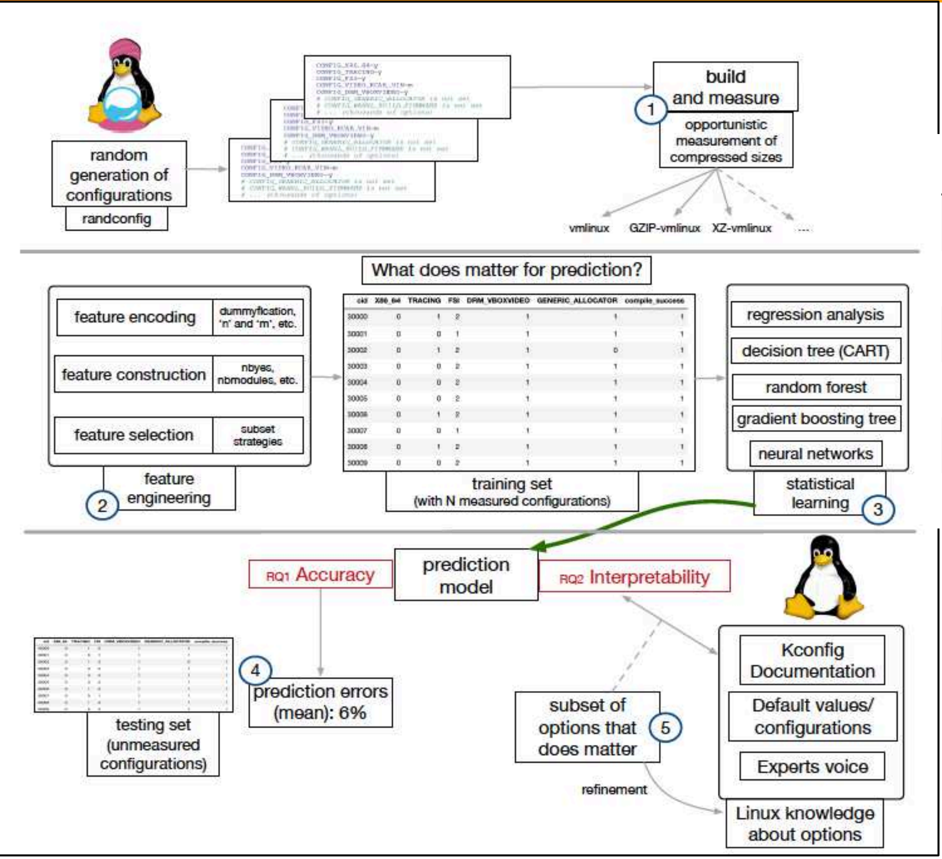
Application 2: Kernel Size Prediction



```
CONFIG_X86_64=y
CONFIG_TRACING=y
CONFIG_FSI=y
CONFIG_VIDEO_RCAR_VIN=m
CONFIG_DRM_VBOXVIDEO=y
# CONFIG_GENERIC_ALLOCATOR is not set
# CONFIG_WANXL_BUILD_FIRMWARE is not set
# ... (thousands of options)
```

cid	X86_64	TRACING	FSI	DRM_VBOXVIDEO	GENERIC_ALLOCATOR	compile_success
30000	0	1	2	1	1	1
30001	0	0	1	1	1	1
30002	0	1	2	1	0	1
30003	0	0	2	1	1	1
30004	0	0	2	1	1	1
30005	0	0	2	1	1	1
30006	0	1	2	1	1	1
30007	0	0	1	1	1	1
30008	0	1	2	1	1	1
30009	0	0	2	1	1	1

Application 2: Kernel Size Prediction

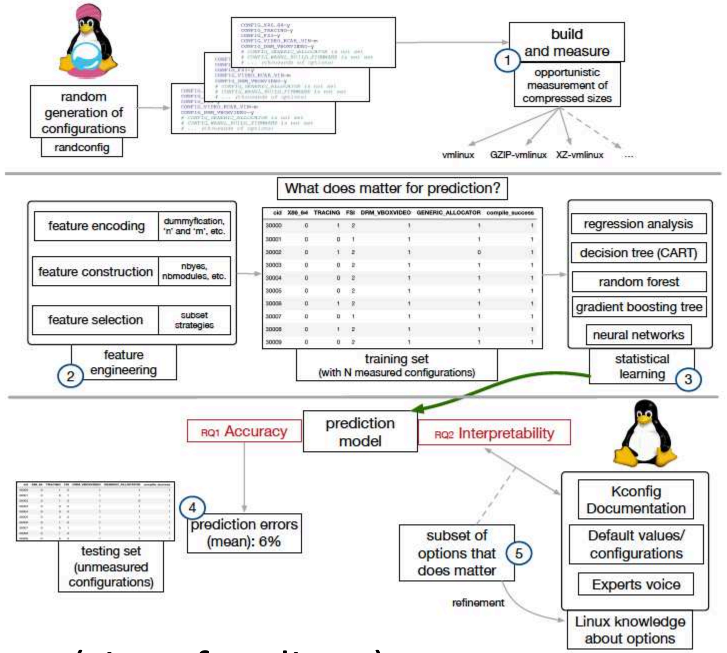


vmlinux and compressed sizes

	GZIP	BZIP2	LZMA	XZ	LZO	LZ4
GZIPo	0	-28.1465	17.6087	25.5951	-7.48979	-12.3437
BZIP2o	41.0556	0	65.3317	76.2405	30.6506	23.8874
LZMAo	-14.8725	-39.0396	0	6.74528	-21.2054	-25.3171
XZo	-20.0819	-42.8681	-6.15874	0	-26.0152	-29.8666
LZOo	8.14584	-22.1959	27.2664	35.9318	0	-5.26847
LZ4o	14.2047	-17.7728	34.4445	43.6185	5.57607	0

```
config KERNEL_XZ
        bool "XZ"
        depends on HAVE_KERNEL_XZ
        help
          XZ uses the LZMA2 algorithm and instruction set specific
          BCJ filters which can improve compression ratio of executable
          code. The size of the kernel is about 30% smaller with XZ in
          comparison to gzip. On architectures for which there is a BCJ
          filter (i386, x86_64, ARM, IA-64, PowerPC, and SPARC), XZ
          will create a few percent smaller kernel than plain LZMA.
```

Application 2: Kernel Size Prediction



(size of vmlinux)
Max: 1,698.14Mb
Min: 7Mb (tinyconfig)

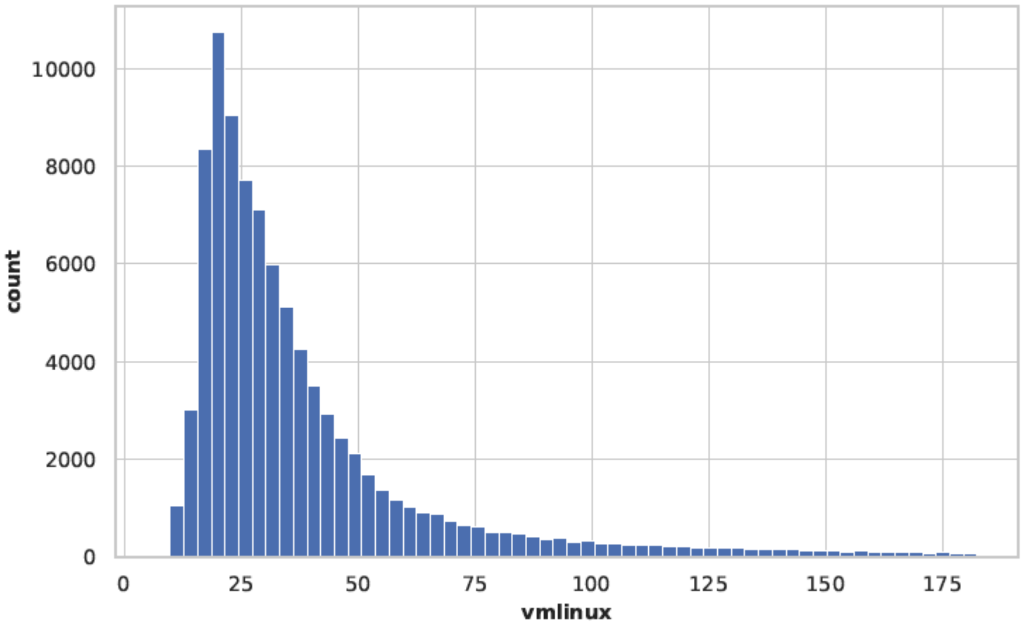
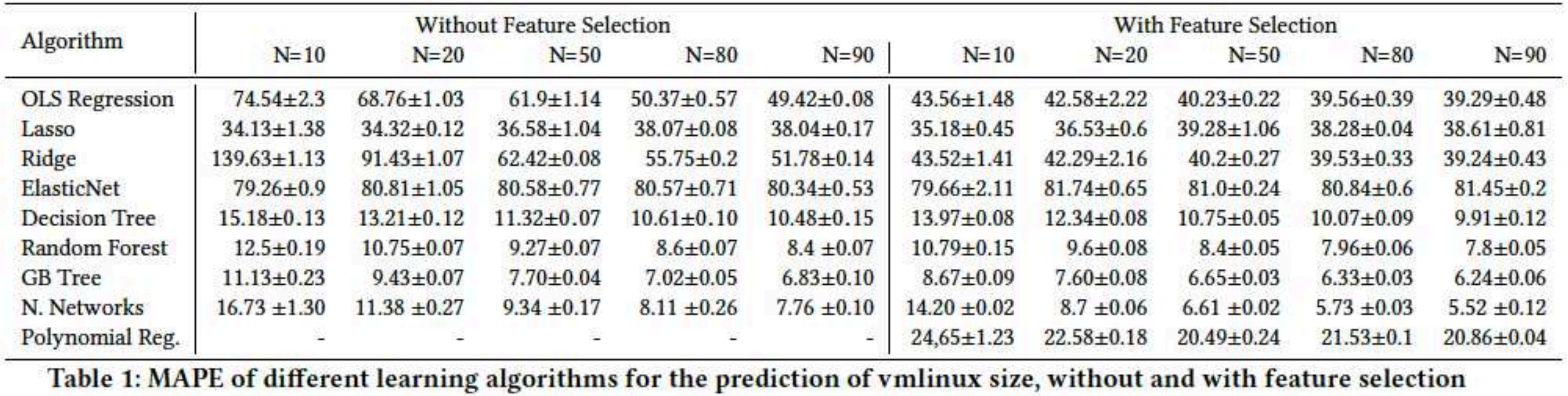


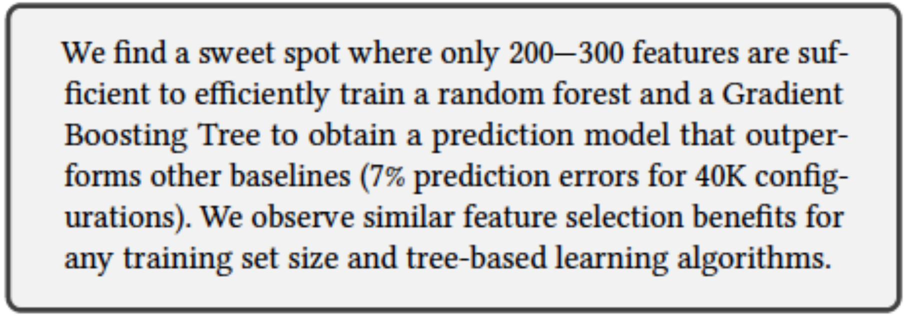
Figure 4: Distribution of size (in Mb) without outliers

Application 2: Kernel Size Prediction



Algorithm	Without Feature Selection					With Feature Selection				
	N=10	N=20	N=50	N=80	N=90	N=10	N=20	N=50	N=80	N=90
OLS Regression	74.54±2.3	68.76±1.03	61.9±1.14	50.37±0.57	49.42±0.08	43.56±1.48	42.58±2.22	40.23±0.22	39.56±0.39	39.29±0.48
Lasso	34.13±1.38	34.32±0.12	36.58±1.04	38.07±0.08	38.04±0.17	35.18±0.45	36.53±0.6	39.28±1.06	38.28±0.04	38.61±0.81
Ridge	139.63±1.13	91.43±1.07	62.42±0.08	55.75±0.2	51.78±0.14	43.52±1.41	42.29±2.16	40.2±0.27	39.53±0.33	39.24±0.43
ElasticNet	79.26±0.9	80.81±1.05	80.58±0.77	80.57±0.71	80.34±0.53	79.66±2.11	81.74±0.65	81.0±0.24	80.84±0.6	81.45±0.2
Decision Tree	15.18±0.13	13.21±0.12	11.32±0.07	10.61±0.10	10.48±0.15	13.97±0.08	12.34±0.08	10.75±0.05	10.07±0.09	9.91±0.12
Random Forest	12.5±0.19	10.75±0.07	9.27±0.07	8.6±0.07	8.4 ±0.07	10.79±0.15	9.6±0.08	8.4±0.05	7.96±0.06	7.8±0.05
GB Tree	11.13±0.23	9.43±0.07	7.70±0.04	7.02±0.05	6.83±0.10	8.67±0.09	7.60±0.08	6.65±0.03	6.33±0.03	6.24±0.06
N. Networks	16.73 ±1.30	11.38 ±0.27	9.34 ±0.17	8.11 ±0.26	7.76 ±0.10	14.20 ±0.02	8.7 ±0.06	6.61 ±0.02	5.73 ±0.03	5.52 ±0.12
Polynomial Reg.	-	-	-	-	-	24,65±1.23	22.58±0.18	20.49±0.24	21.53±0.1	20.86±0.04

Table 1: MAPE of different learning algorithms for the prediction of vmlinux size, without and with feature selection



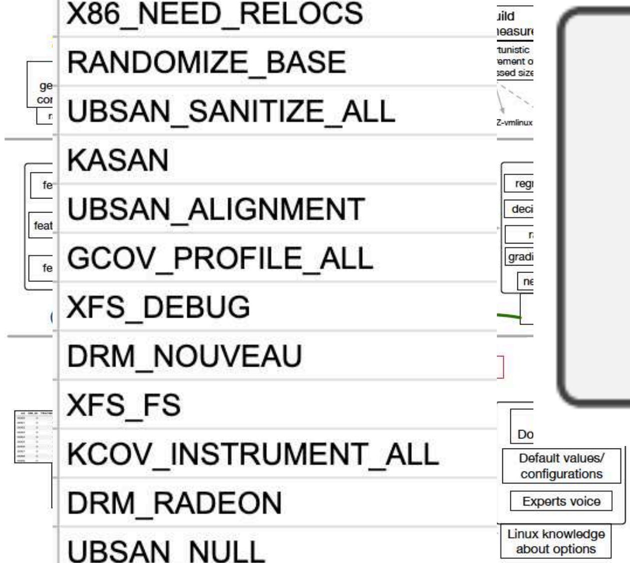
We find a sweet spot where only 200—300 features are sufficient to efficiently train a random forest and a Gradient Boosting Tree to obtain a prediction model that outperforms other baselines (7% prediction errors for 40K configurations). We observe similar feature selection benefits for any training set size and tree-based learning algorithms.

up to ~3% for compressed kernels sizes!

Towards smart configuration assistant (optimizer/recommender/ configurator)

on 2: Kernel Size Prediction

DEBUG_INFO
#yes
DEBUG_INFO_REDUCED
DEBUG_INFO_SPLIT
X86_NEED_RELOCS
RANDOMIZE_BASE
UBSAN_SANITIZE_ALL
KASAN
UBSAN_ALIGNMENT
GCOV_PROFILE_ALL
XFS_DEBUG
DRM_NOUVEAU
XFS_FS
KCOV_INSTRUMENT_ALL
DRM_RADEON
UBSAN_NULL
MAXSMP
BLK_MQ_PCI
DRM_AMDGPU
SCSI_ISCSI_ATTRS
MDIO
X86_VSMP



Thanks to our prediction model, we have effectively identified a list of important features that is consistent with the options and strategy of tinyconfig, the Kconfig documentation, and Linux knowledge. We also found options that can be used to refine or augment the documentation.

Towards improved documentation/default config. and informed configurations' decisions

Challenges

- Retrospectively and despite our investment, we found relatively few bugs of Linux
  - Is it due to the way we sample?
  - Is it due to the stable version of Linux we chose?
  - Is it due to the high-quality of Linux, its contributors and its industry-strength, community-based effort?

Challenges

- Sampling is based on randconfig
  - randconfig does not produce uniform random samples
  - hypothesis: the testing “community” has over-fitted randconfig
- We need other sampling strategies!
  - Uniform (but SAT-based techniques should be improved)
  - Coverage-based sampling (e.g., t-wise)
  - Knowledge-based sampling

Challenges

- The cost of gathering data is important (15K+ hours of computation)
- Incremental build of configurations
- Bugs do not transfer well
- However, kernel size “knowledge” may transfer
  - Instead of starting from scratch, we can transfer a prediction model for another version of Linux (ongoing work)

Challenges

- Kernel CI / 0-day
  - Our focus: testing **configurations** in the large
  - Complementary!
  - **Learning** techniques can be used in both contexts
  - Sharing data
- Unify the force!

Challenges

- “Smart” build infrastructure
  - Other properties (e.g., warnings, boot, security)
- With devs/contributors in the loop
  - We need knowledge to validate our learning model
  - We need knowledge to apply “smart” sampling
  - We aim to produce actionable knowledge
- TUXML needs you!

Conclusion (feedbacks welcome!)

- Learning From Thousands of Build Failures of Linux Kernel Configurations
  - Mathieu Acher, Hugo Martin, Juliana Alves Pereira, Arnaud Blouin, Djamel Eddine Khelladi, Jean-Marc Jézéquel
  - https://hal.inria.fr/hal-02147012
- Learning Very Large Configuration Spaces: What Matters for Linux Kernel Sizes
  - Mathieu Acher, Hugo Martin, Juliana Pereira, Arnaud Blouin, Jean-Marc Jézéquel, Djamel Eddine Khelladi, Luc Lesoil, Olivier Barais
  - https://hal.inria.fr/hal-02314830

Some related work

- Julia Lawall and Gilles Muller “JMake: Dependable Compilation for Kernel Janitors.” In 47th Annual IEEE/IFIP International Conference on Dependable Systems and Networks, DSN 2017
- Iago Abal, Claus Brabrand, and Andrzej Wasowski “42 variability bugs in the linux kernel: a qualitative analysis”. In ACM/IEEE International Conference on Automated Software Engineering, ASE’14
- Jean Melo, Elvis Flesborg, Claus Brabrand, and Andrzej Wasowski “A Quantitative Analysis of VariabilityWarnings in Linux”. In Proceedings of the Tenth International Workshop on Variability Modelling of Software-intensive Systems (VaMoS’16)
- Sarah Nadi, Thorsten Berger, Christian Kästner, and Krzysztof Czarnecki ”Where Do Configuration Constraints Stem From? An Extraction Approach and an Empirical Study” IEEE Trans. Software Eng., 2016
- Minghui Zhou, Qingying Chen, Audris Mockus, and Fengguang Wu “On the Scalability of Linux Kernel Maintainers’ Work”. In Proceedings of the 2017 11th Joint Meeting on Foundations of Software Engineering (ESEC/FSE 2017)

Some related work

- Axel Halin, Alexandre Nuttinck, Mathieu Acher, Xavier Devroey, Gilles Perrouin, Benoit Baudry: Test them all, is it worth it? Assessing configuration sampling on the JHipster Web development stack. Empirical Software Engineering 24(2): 674-717 (2019)
- Quentin Plazar, Mathieu Acher, Gilles Perrouin, Xavier Devroey, Maxime Cordy: Uniform Sampling of SAT Solutions for Configurable Systems: Are We There Yet? ICST 2019: 240-251
- Juliana Alves Pereira, Hugo Martin, Mathieu Acher, Jean-Marc Jézéquel, Goetz Botterweck, Anthony Ventresque: Learning Software Configuration Spaces: A Systematic Literature Review. CoRR abs/1906.03018 (2019)
- Paul Temple, Mathieu Acher, Jean-Marc Jézéquel, Olivier Barais: Learning Contextual-Variability Models. IEEE Software 34(6): 64-70 (2017)
- Austin Mordahl, Jeho Oh, Ugur Koc, Shiyi Wei, Paul Gazzillo: An empirical study of real-world variability bugs detected by variability-oblivious tools. ESEC/SIGSOFT FSE 2019: 50-61

Thanks!

- DiverSE research team http://diverse-team.fr
  - Hugo Martin, Juliana Alves Pereira, Arnaud Blouin, Jean-Marc Jézéquel, Djamel Eddine Khelladi, Luc Lesoil, Olivier Barais
- TUXML team at ISTIC / University of Rennes 1
  - Paul Saffray, Alexis Le Masle, Michaël Picard, Corentin Chédotal, Gwendal Didot, Dorian Dumanget, Antonin Garret, Erwan Le Flem, Pierre Le Luron, Mickaël Lebreton, Fahim Merzouk, Valentin Petit, Julien Royon Chalendard, Cyril Hamon, Luis Thomas, Alexis Bonnet
- IGRIDA http://igrida.gforge.inria.fr
- Tim Bird (Sony) and Greg Kroah-Hartman (Linux foundation)
- Julia Lawall (for challenging us to attend ELC!)

Intrigued by Tux logos?

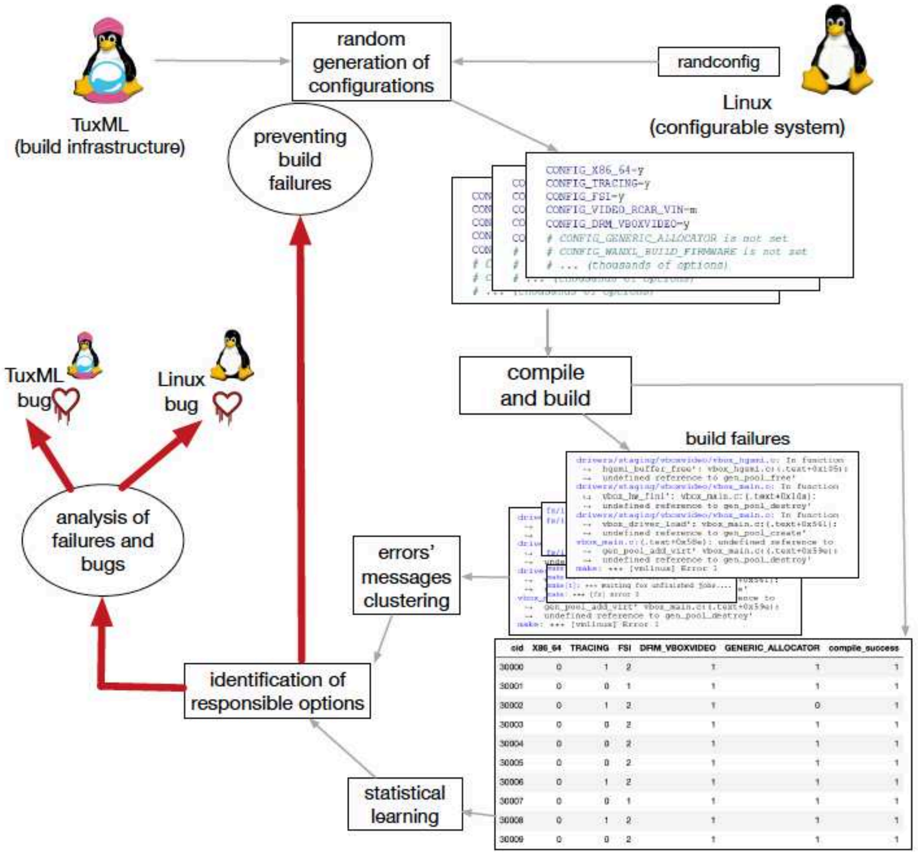
Have a look and don't hesitate to contribute!

https://github.com/diverse-project/tuxart

Side project: Tux generator out of arbitrary Linux kernel configurations (.config)

Khaled Arsalane
Eliot Marie
Pierre Pouteau
Zakariae Boukhchen
Richard Faraji-Huon
Mathieu Acher

Application 1: “Smart” build infrastructure


TuxML
(build infrastructure)
random generation of configurations
randconfig
Linux
(configurable system)
preventing build failures
compile and build
build failures
TuxML bug
Linux bug
analysis of failures and bugs
errors' messages clustering
identification of responsible options
statistical learning

```
CONFIG_X86_64=y
CONFIG_TRACING=y
CONFIG_FSI=y
CONFIG_VIDEO_RCAR_VIN=m
CONFIG_DRM_VBOXVIDEO=y
# CONFIG_GENERIC_ALLOCATOR is not set
# CONFIG_WANXL_BUILD_FIRMWARE is not set
# ... (thousands of options)
```

```
drivers/staging/vboxvideo/vbox_hgsmi.c: In function
 →  hgsmi_buffer_free': vbox_hgsmi.c:(.text+0x185):
 →  undefined reference to gen_pool_free'
drivers/staging/vboxvideo/vbox_main.c: In function
 →  vbox_hw_fini': vbox_main.c:(.text+0x1da):
 →  undefined reference to gen_pool_destroy'
drivers/staging/vboxvideo/vbox_main.c: In function
 →  vbox_driver_load': vbox_main.c:(.text+0x541):
 →  undefined reference to gen_pool_create'
vbox_main.c:(.text+0x58e): undefined reference to
 →  gen_pool_add_virt' vbox_main.c:(.text+0x59e):
 →  undefined reference to gen_pool_destroy'
make: *** [vmlinux] Error 1
```

```
make[1]: *** waiting for unfinished jobs....
make: *** [fs] error 2
```

cid	X86_64	TRACING	FSI	DRM_VBOXVIDEO	GENERIC_ALLOCATOR	compile_success
30000	0	1	2	1	1	1
30001	0	0	1	1	1	1
30002	0	1	2	1	0	1
30003	0	0	2	1	1	1
30004	0	0	2	1	1	1
30005	0	0	2	1	1	1
30006	0	1	2	1	1	1
30007	0	0	1	1	1	1
30008	0	1	2	1	1	1
30009	0	0	2	1	1	1

5.83% of build failures
BUT
only due to 16 configuration bugs of Linux and 3 configuration bugs of… TUXML

We come to this insight thanks to our learning procedure

Embedded Linux Conference

Europe