# KernelSBOM

Reconstructing Linux Kernel Builds into Trusted SPDX Bills of Materials

## About myself

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# This is
# Work in Progress

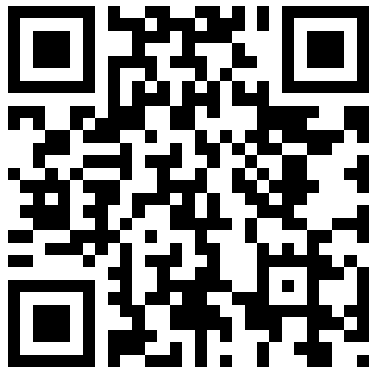
(not just the slides, also the project)

Task:

# Create an SBOM for a Linux Kernel Build

# The KernelSbom tool

A tool that analyzes a kernel build and produces SBOM documents



https://github.com/TNG/KernelSbom

(The name and home might change)

## Example Call:

```
$ export SRCARCH=x86
$ python3 sbom/sbom.py \
    --src-tree path/to/linux \
    --obj-tree path/to/kernel_build \
    --roots arch/x86/boot/bzImage \
    --generate-spdx
```

## Step 1

# Analyze the Build

We start with "roots" and build a graph. Roots are usually the distributable artifacts generated by the build like `arch/x86/boot/bzImage` and `*.ko` files.

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`.cmd` files look like:

```
savedcmd_${target} := ${make-cmd}
```

or

```
savedcmd_${target} := ${make-cmd}

source_${target} := ${source}

deps_${target} := \
    ${dependency1} \
    ${dependency2} \
    ${dependency3} \
    ...
```

## Parsing the savedcmd_${target} command

Example: `arch/x86/boot/bzImage`

```
$ cat arch/x86/boot/.bzImage.cmd
savedcmd_arch/x86/boot/bzImage := ( \
        dd if=arch/x86/boot/setup.bin bs=4k conv=sync status=none; \
        cat arch/x86/boot/vmlinux.bin \
    ) >arch/x86/boot/bzImage
```

parsing the command reveals that this output depends on:

- `arch/x86/boot/setup.bin`
- `arch/x86/boot/vmlinux.bin`

## Parsing the savedcmd_${target} command

Another example: `arch/x86/boot/compressed/vmlinux`

```
$ cat arch/x86/boot/compressed/.vmlinux.cmd
savedcmd_arch/x86/boot/compressed/vmlinux := \
    ld -m elf_i386 --no-ld-generated-unwind-info
[...]
        arch/x86/boot/compressed/kernel_info.o \
        arch/x86/boot/compressed/head_32.o \
        arch/x86/boot/compressed/misc.o \
        arch/x86/boot/compressed/string.o \
        arch/x86/boot/compressed/cmdline.o \
        arch/x86/boot/compressed/error.o \
        arch/x86/boot/compressed/piggy.o \
        arch/x86/boot/compressed/cpuflags.o \
        -o arch/x86/boot/compressed/vmlinux
```

Depends on:

- `arch/x86/boot/compressed/kernel_info.o`
- `arch/x86/boot/compressed/head_32.o`
- ...

## Parsing source_${target} and deps_${target}

Example: `arch/x86/boot/compressed/kernel_info.o`

```
$ cat arch/x86/boot/compressed/.kernel_info.o.cmd
savedcmd_arch/x86/boot/compressed/kernel_info.o := gcc -Wp,-MMD,arch/x86/boot/compressed/.kernel_info.o.d -nostdinc -I.

source_arch/x86/boot/compressed/kernel_info.o := ../arch/x86/boot/compressed/kernel_info.S

deps_arch/x86/boot/compressed/kernel_info.o := \
    ../include/linux/compiler-version.h \
    $(wildcard include/config/CC_VERSION_TEXT) \
    ../include/linux/kconfig.h \
    $(wildcard include/config/CPU_BIG_ENDIAN) \
    $(wildcard include/config/BOOGER) \
    $(wildcard include/config/FOO) \
    ../include/linux/hidden.h \
    ../arch/x86/include/uapi/asm/bootparam.h \
    ../arch/x86/include/asm/setup_data.h \
   ../arch/x86/include/uapi/asm/setup_data.h \

arch/x86/boot/compressed/kernel_info.o: $(deps_arch/x86/boot/compressed/kernel_info.o)

$(deps_arch/x86/boot/compressed/kernel_info.o):
```

## We also search for `.incbin` statements in `.S` files

These dependencies are not transparent in the `.cmd` files. An example is:

```
$ cat arch/riscv/boot/loader.S
/* SPDX-License-Identifier: GPL-2.0 */

  .align 4
  .section .payload, "ax", %progbits
  .globl _start
_start:
  .incbin "arch/riscv/boot/Image"
```

This includes the build output `arch/riscv/boot/Image`, which itself has a `.cmd` file which can be followed further.

## Some dependencies are hardcoded

Makefiles and Kbuild files are not parsed due to their complex structure. Dependencies only defined in these files need to be hardcoded. The current list that is sufficient for tinyconfig is:

```
HARDCODED_DEPENDENCIES: dict[str, list[str]] = {
    "include/generated/rq-offsets.h": ["kernel/sched/rq-offsets.s"],
    "include/generated/bounds.h": ["kernel/bounds.s"],
    "include/generated/asm-offsets.h": ["arch/{arch}/kernel/asm-offsets.s"],
    "kernel/sched/rq-offsets.s": ["include/generated/asm-offsets.h"],
}
```

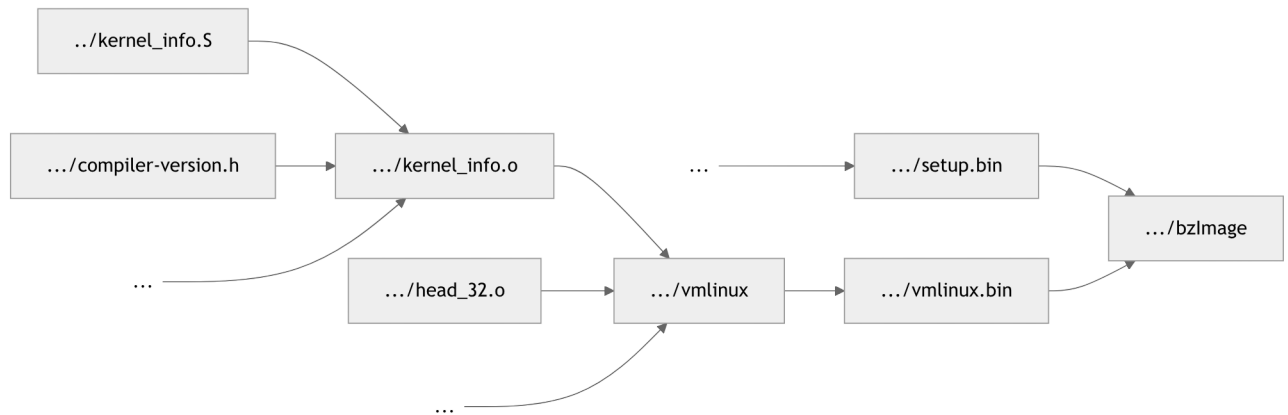
🚧 **See #50 for details**

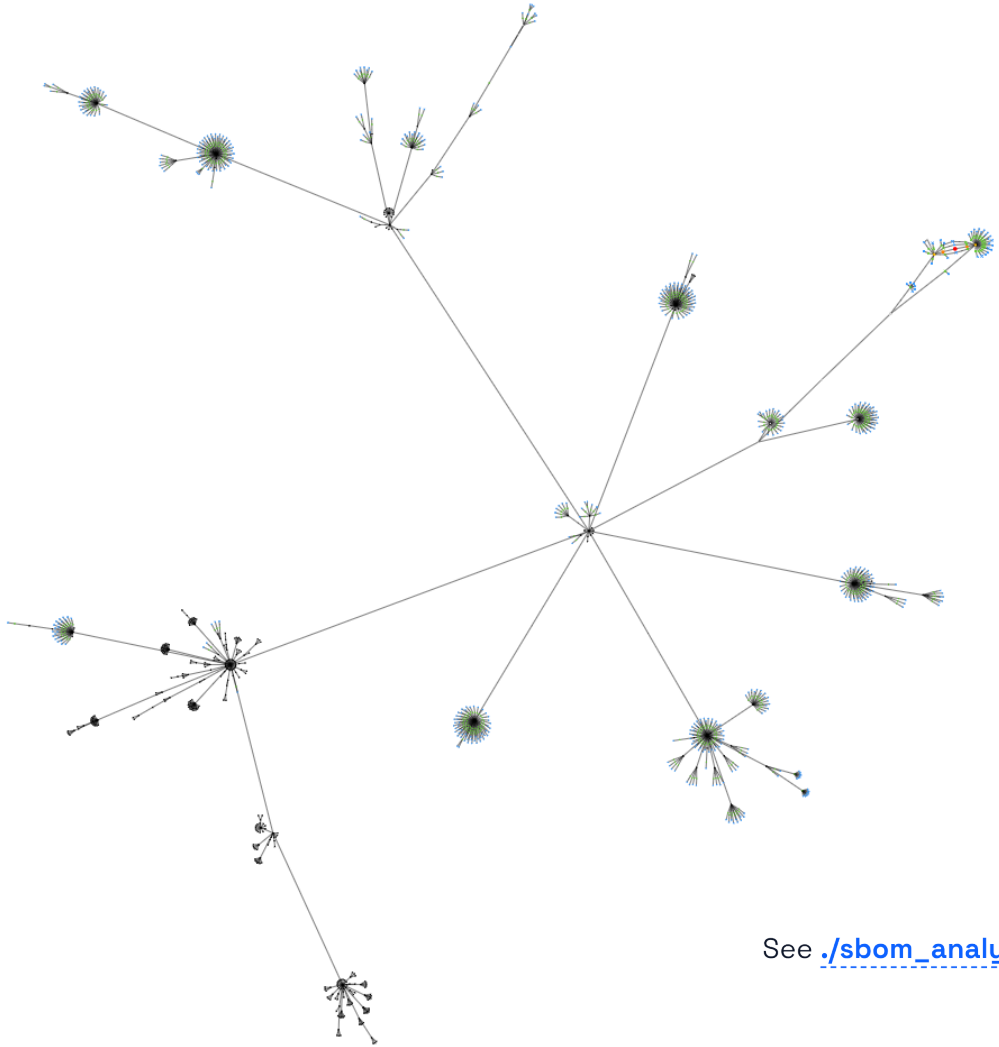
This list is incomplete.

# Summary

The graph is created by starting at roots and finding dependencies with the following strategies:

- Parsing the `.cmd` files
  - Parsing the savedcmd_${target} command
  - Parsing source_${target} and deps_${target}
- Parsing the actual files
  - Parsing `.incbin` statements in `.S` files
- Applying some hardcoded dependencies





See ./sbom_analysis/cmd_graph_visualization/

# Validation of completeness

One of the outputs of the tool is a list of used source files. The interesting question is whether this list is complete and correct.

We did two checks for a few configurations to validate whether the graph is complete:

1. We dropped all source files that were not included in the graph and tested that the build still succeeds
2. We compared the files in the graph with the list of opened files during a compilation run analyzed with `strace` and see a 99.49% overlap

🚧 **This is not yet at 100%**

see #54 and especially #95

# Step 2
# Serialize as SBOM

Using the SPDX 3.0.1 standard.

- Established and widely used.
- A Linux Foundation project.
- Is targeting ISO again.
- Uses a JSON-LD serialization that we can just treat as JSON.





## The System Package Data Exchange® (SPDX®) Specification Version 3.0.1



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# Three interlinked files

**Output SBOM:** `sbom-output.spdx.json`

**Source SBOM:** `sbom-source.spdx.json`

**Build SBOM:** `sbom-build.spdx.json`

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Describes the packages for the Linux kernel and the kernel modules.

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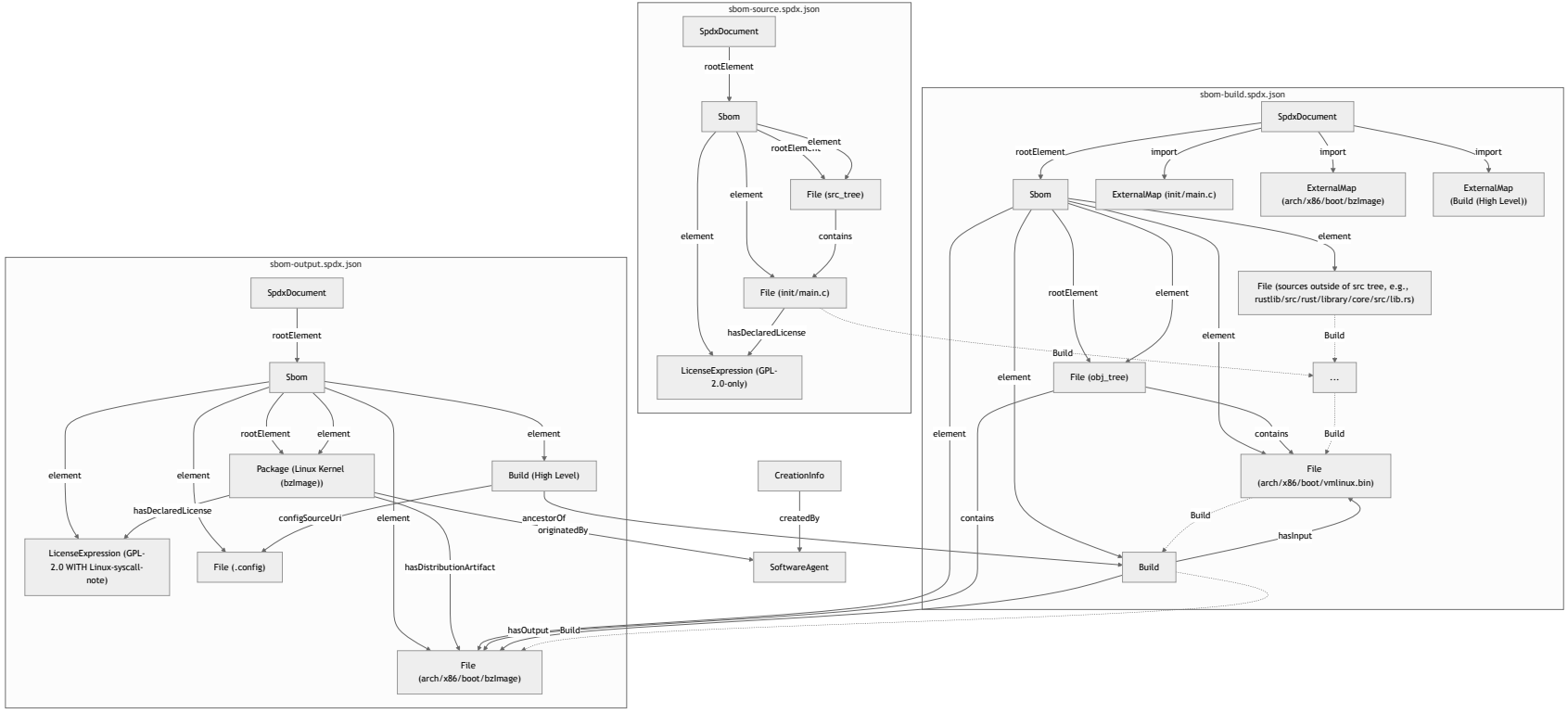
## Build SBOM: `sbom-build.spdx.json`

Links the sources to the output artifacts and represents the build graph.

> 🚧 **This only works with out-of-tree builds right now**
>
> The heuristic to identify which files are source is whether they are in the source directory.

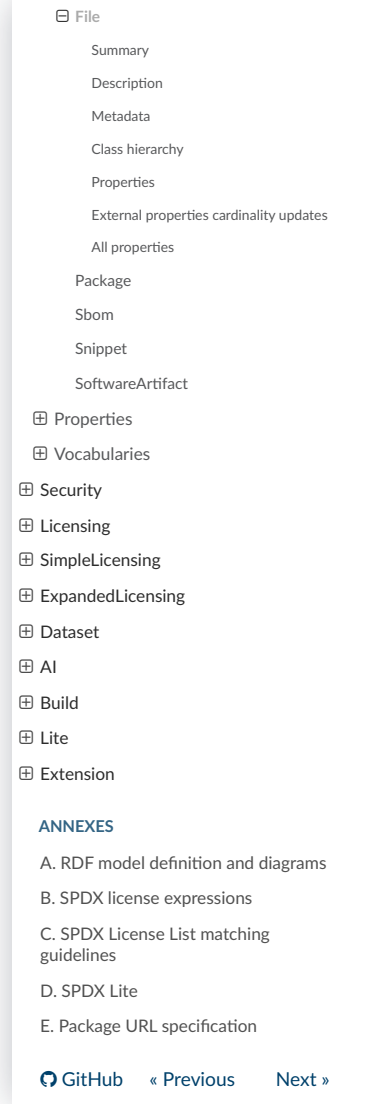
# Internal structure:

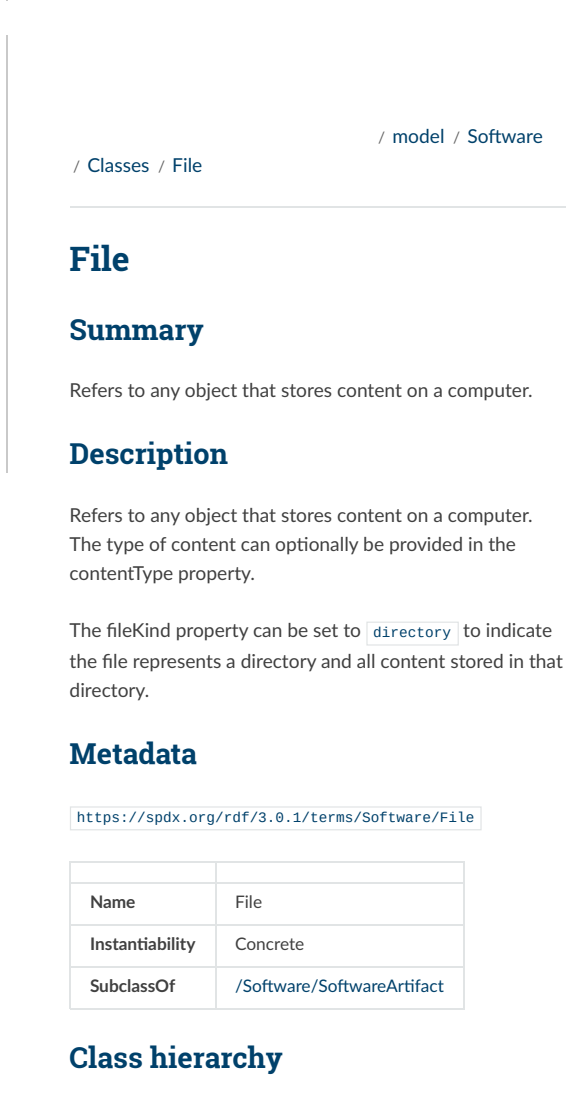


# Source SBOM

Basically a list of the used files together with more metadata that is collected via static analysis

- extract declared license from `SPDX-License-Identifier:`
- guess file-type based on file extension and location
- compute file hashes



# Source SBOM

Example entry for `init/main.c`:

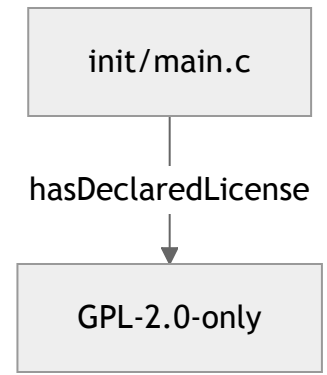

```
{
  "type": "software_File",
  "spdxId": "s:121",
  "creationInfo": "_:creationinfo",
  "name": "init/main.c",
  "verifiedUsing": [
    {
      "type": "Hash",
      "hashValue": "0c8bdff5df4e99c50cf7a7b95c1798206a39d93edd97bd605e7cc3ccfdd58ec9",
      "algorithm": "sha256"
    }
  ],
  "software_primaryPurpose": "source",
  "software_contentIdentifier": [
    {
      "type": "software_ContentIdentifier",
      "software_contentIdentifierType": "gitoid",
      "software_contentIdentifierValue": "fab4f599c035e73483eaeae101adaff4f5d72f2b"
    }
  ]
}
```

# Source SBOM

The file from the previous slide ( `"s:121"` ) has the declared license GPL-2.0-only, which is encoded via a Relationship to a LicenseExpression:

```
{
  "type": "Relationship",
  "spdxId": "s:4415",
  "creationInfo": "_:creationinfo",
  "relationshipType": "hasDeclaredLicense",
  "from": "s:121",
  "to": [
    "s:4301"
  ]
}
```

```
{
  "type": "simplelicensing_LicenseExpression",
  "spdxId": "s:4301",
  "creationInfo": "_:creationinfo",
  "simplelicensing_licenseExpression": "GPL-2.0-only"
}
```



# Output SBOM


```
{
  "type": "software_Package",
  "spdxId": "o:2",
  "creationInfo": "_:creationinfo",
  "name": "Linux Kernel (bzImage)",
  "comment": "Architecture=x86",
  "originatedBy": [ "p:0" ],
  "software_primaryPurpose": "application",
  "software_copyrightText": ...,
  "software_packageVersion": "6.18.0"
}
```

```
{
  "type": "software_Package",
  "spdxId": "o:3",
  "creationInfo": "_:creationinfo",
  "name": "efivarfs.ko",
  "comment": "Architecture=x86",
  "originatedBy": [ "p:0" ],
  "software_primaryPurpose": "module",
  "software_copyrightText": ...,
  "software_packageVersion": "6.18.0"
}
```






## Package

### Summary

Refers to any unit of content that can be associated with a distribution of software.

### Description

A package refers to any unit of content that can be associated with a distribution of software.

Typically, a package is composed of one or more files.

Any of the following non-limiting examples may be (but are not required to be) represented in SPDX as a package:

- a tarball, zip file or other archive
- a directory or sub-directory
- a separately distributed piece of software which another Package or File uses or depends upon (e.g., a Python package, a Go module, ...)
- a container image, and/or each image layer within a container image
- a collection of one or more sub-packages
- a Git repository snapshot from a particular point in time

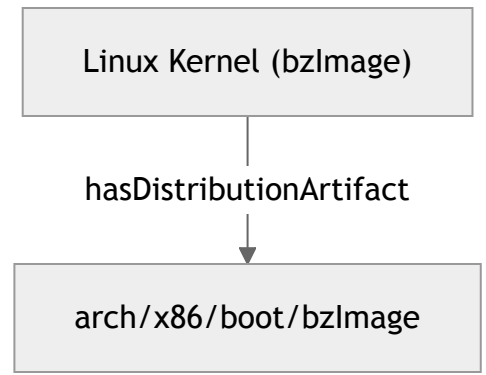
Note that some of these could be represented in SPDX as a file as well.

# Output SBOM

The Package is linked to a File as its DistributionArtifact via a Relationship.


```
{
  "type": "Relationship",
  "spdxId": "o:12",
  "creationInfo": "_:creationinfo",
  "relationshipType": "hasDistributionArtifact",
  "from": "o:2",
  "to": [
    "b:7"
  ]
}
```

```
{
  "type": "software_File",
  "spdxId": "b:7",
  "creationInfo": "_:creationinfo",
  "name": "arch/x86/boot/bzImage",
[...]
```

# Output SBOM

A Build element contains the high-level view of the build. The Build is linked to the outputs with the `hasOutput` Relationship.


```
{
  "type": "build_Build",
  "spdxId": "o:3",
  "creationInfo": "_:creationinfo",
  "build_buildType": "urn:spdx.dev:Kbuild",
  "build_buildId": "o:3",
  "build_environment": [
    { "type": "DictionaryEntry", "key": "SRCARCH", "value": "x86" },
    { "type": "DictionaryEntry", "key": "srcroot", "value": ".." },
    [...]
  ],
  "build_configSourceUri": [ "o:2" ],
  "build_configSourceDigest": [
    {
      "type": "Hash",
      "hashValue": "837d6caddc50002189ef7dcac28b79a2165166310c7b8a85278534a76dc8abce",
      "algorithm": "sha256"
    }
  ]
}
```

# Build SBOM

The Build SBOM contains many low-level Build elements, describing the detailed structure of the Build.

- Every build stores the `savedcmd_` content as comment
- The high level build from the output SPDX is connected to the low level builds via the `ancestorOf` Relationship

This ties the Source SBOM together with the Output SBOM.





## Build

## Profile information

### Summary

The Build Profile defines the set of information required to describe an instance of a Software Build.

### Description

A Software Build is defined here as the act of converting software inputs into software artifacts using software build tools. Inputs can include source code, config files, artifacts that are build environments, and build tools. Outputs can include intermediate artifacts to other build inputs or the final artifacts.

The Build profile provides a subclass of Element called Build.

It also provides a minimum set of required Relationship Types from the Core profile:

- hasInput: Describes the relationship from the Build element to its inputs.
- hasOutput: Describes the relationship from the Build element to its outputs.

# Build SBOM

A Build is linked via Relationships to its inputs and outputs.


```
{
  "type": "build_Build",
  "spdxId": "b:4151",
  "creationInfo": "_:creationinfo",
  "comment": "arch/x86/boot/compressed/mkpiggy arch/x86/boot/compressed/vmlinux.bin.gz > arch/x86/boot/compressed/piggy
  "build_buildType": "urn:spdx.dev:Kbuild",
  "build_buildId": "urn:spdx.dev:987b9938-c26a-490d-ae00-54630d81262c/output/3"
}
```

```
{
  "type": "Relationship",
  "spdxId": "b:4152",
  "creationInfo": "_:creationinfo",
  "relationshipType": "hasInput",
  "from": "b:4151",
  "to": [ "b:140" ]
}
```

```
{
  "type": "Relationship",
  "spdxId": "b:4153",
  "creationInfo": "_:creationinfo",
  "relationshipType": "hasOutput",
  "from": "b:4151",
  "to": [ "b:116" ]
}
```

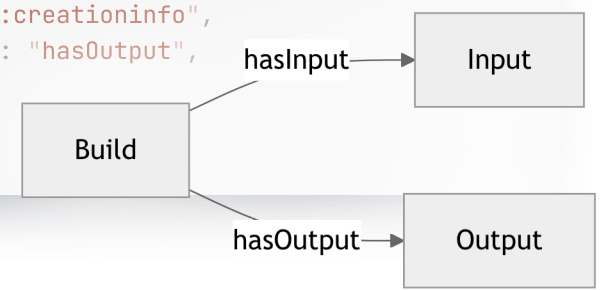
# Build SBOM

A Build is linked via Relationships to its inputs and outputs.


```
{
  "type": "build_Build",
  "spdxId": "b:4151",
  "creationInfo": "_:creationinfo",
  "comment": "arch/x86/boot/compressed/mkpiggy arch/x86/boot/compressed/vmlinux.bin.gz > arch/x86/boot/compressed/piggy
  "build_buildType": "urn:spdx.dev:Kbuild",
  "build_buildId": "urn:spdx.dev:987b9938-c26a-490d-ae00-54630d81262c/output/3"
}
```

```
{
  "type": "Relationship",
  "spdxId": "b:4152",
  "creationInfo": "_:creationinfo",
  "relationshipType": "hasInput",
  "from": "b:4151",
  "to": [ "b:140" ]
}
```

```
{
  "type": "Relationship",
  "spdxId": "b:4153",
  "creationInfo": "_:creationinfo",
  "relationshipType": "hasOutput",
  "from": "b:4151",
  "to": [ "b:116" ]
}
```

# Reproducible

The generation is deterministic and timestamps and generated IDs can be controlled externally.

```
export SRCARCH=x86
python3 sbom/sbom.py \
    --src-tree path/to/linux \
    --obj-tree path/to/kernel_build \
    --roots arch/x86/boot/bzImage \
    --generate-spdx \
    --spdxId-uuid bd3ab149-b4a7-4993-8fb4-5c99093c4f28 \
    --created "2025-12-03 11:30:00"
```

# Next steps

# Get it upstream

The idea is

- to contribute the subdirectory `/sbom` from the KernelSbom project to `/tools/sbom`
- add a config option `SBOM` to enable it
- produce the SPDX files in output directory

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## Proof of concept:

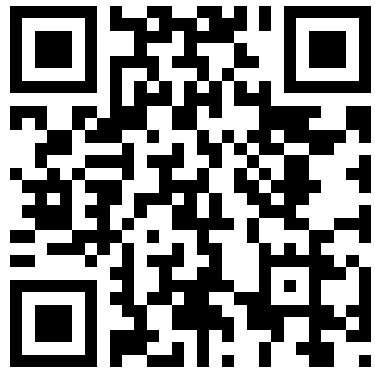
Get the branch `kernelsbom-integration` from https://github.com/augelu-tng/linux.git.

```
$ make defconfig O=kernel_build
$ scripts/config --file kernel_build/.config --enable SBOM
$ make O=kernel_build -j$(nproc)
```

# Further development and next steps

- Let it have contact with the real world. We want feedback.
- Support for more architectures, like RISC-V, PowerPC, and s390.
- Integration with other tools and ecosystems.

# Thank You!



https://github.com/TNG/KernelSbom