Secure Sharing Between Untrusted Users in a Transparent Source/Binary Deployment Model

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Goal

Create a *package management system* that allows *any user* to install software.

Package management models

Traditional Unix package managers

- RPM, Apt, FreeBSD Ports, Gentoo Portage, ...
- Manage dependencies
- Only the administrator can install packages
- ... since they go into global directories like **/usr/bin**
- Packages are *shared* between users

Monolithic packaging systems

- Windows, Mac OS X
- Everybody can install packages
- But there is no sharing (unless explicitly arranged)

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Monolithic packaging systems

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Sharing

Why do we want sharing?

- More efficient use of resources
- Especially due to common dependencies: $\Theta(N + M)$ instead of $\Theta(N \times M)$

The problem

- Users may be mutually *untrusted*
- If Alice installs Firefox, then Bob may not want to use it; it may contain a Trojan horse

Typical untrusted environments

- Student login servers
- Hosting providers
- Computational grids

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This paper

This paper extends the *Nix deployment system* to support secure sharing between untrusted users.

The Nix Deployment System

- Central idea: store all components in isolation.
- Unique paths:

```
/nix/store/jjp9pirx8b3nqs9k...-firefox
```

which is an SHA-256 hash of **all** inputs used to build the component:

- Sources
- Libraries
- Compilers
- Build scripts
- Build parameters
- System type
- ...

- **Prevent** undeclared **build time** dependencies.
- **Scan** for **runtime** dependencies.
- Deploy only **closures** under the **depends-on** relation.

Nix store

```
/nix/store
├── bd6593219f8dcb63...-gtk+-2.2.4
│   └── lib
│       └── libgtk-x11-2.0.so.0
├── ce2d7d2a41456bab...-wxGTK-2.4.2
│   └── lib
│       └── libwx_gtk2-2.4.so
├── e889db0595672287...-wxPython-2.4.2.4
│   └── (lots of Python bindings)
├── 9ed8c4231bfde4af...-bittorrent-3.4.2
│   └── bin
│       └── btdownloadgui.py
├── 300ccc1a41af3abc...-gtk+-2.4.13
│   └── lib
│       └── libgtk-x11-2.0.so.0
└── f51ec7d5663c735e-zapping-0.7.3
    └── bin
        └── zapping
```

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└── f51ec7d5663c735e-zapping-0.7.3
    └── bin
        └── zapping
```

Unique paths for different versions

Nix expressions

firefox.nix

```
derivation {
  name = "firefox-1.0.7";
  builder = ./builder.sh;
  src = fetchurl {
    url = http://.../firefox-1.0.7-source.tar.bz2;
    md5 = "5704a8c36de84b408e069afb0c5bc1df";
  };
  pkgconfig = derivation { ... };
  gtk = derivation { ... };
}
```

Nix expressions

firefox.nix

```
derivation {
  name = "fi
  builder =
  src = fetchurl {
    url = http://.../firefox-1.0.7-source.tar.bz2;
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  };
  pkgconfig = derivation { ... };
  gtk = derivation { ... };
}
```

Build attributes

Nix expressions

builder.sh

```
source $stdenv/setup

PATH=$pkgconfig/bin:$PATH

tar xvfj $src
cd firefox-*
./configure --prefix=$out --with-gtk=$gtk
make
make install
```

Nix expressions

builder.sh

```
source $stdenv/setup

PATH=$pkgconfig/bin:$PATH

tar xvfj $src
cd firefox-*
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make
make install
```

Environment variables pass locations of dependencies, e.g. **/nix/store/0z017z...-pkgconfig**

Nix expressions

builder.sh

```
source $stdenv/setup

PATH=$pkgconfig/bin:$PATH

tar xvfj $src
cd firefox-*
./configure --prefix=$out --with-gtk=$gtk
make
make install
```

Holds the component's path in the Nix store, e.g. **/nix/store/jjp9pi...-firefox**

User operations

- To build and install Firefox:

```
$ nix-env -f firefox.nix -i firefox
```

- The path of Firefox (e.g., **/nix/store/jjp9pi...-firefox**) is added to the user's **PATH** environment variable.

User operations

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Transparent source/binary deployment

- Nix expressions give a **source deployment model**.
- We get **binary deployment** by sharing pre-built components.
- On the producer side:

```
$ nix-push $(nix-instantiate firefox.nix) \
   http://server/cache
```

- On the client side:

```
$ nix-pull http://server/cache
$ nix-env -f firefox.nix -i firefox
```

- **nix-pull** registers *substitutes*:
  "if I need to build path **/nix/store/jjp9pi...-firefox**,
  I can download and unpack
  http://example.org/jjp9pi...-firefox.nar.bz2 instead"

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Sharing in Nix

Goal

Allow untrusted users to run Nix commands, e.g. installation — *with sharing*

- Users do not have direct write permission to the store
- Build/installation actions are performed by a *system user* on behalf of users
  - I.e., **nix-env** is a **setuid** program or talks to a daemon
- Intended security property: if a Nix expression is trusted, then so is the binary installed by **nix-env -i**

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Sharing in Nix: Example

Alice

- Gets **firefox.nix** from trusted source
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/jjp9pi...-firefox
  Builds it

Nix store

/nix/store
└── **...**

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```
/nix/store
└── jjp9pi...-firefox
    ├── bin
    │   └── firefox
    └── lib
        ├── libxpcom.so
        ├── libmozz.so
        └── ...
```

Sharing in Nix: Example

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- Gets **firefox.nix** from trusted source
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/jjp9pi...-firefox
  Builds it

Bob

- Gets **firefox.nix** from trusted source
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/jjp9pi...-firefox
  Already present!

Nix store

- **/nix/store**
  - **jjp9pi...-firefox**
    - **bin**
      - **firefox**
    - **lib**
      - **libxpcom.so**
      - **libmozz.so**
      - **...**

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- Gets **firefox.nix** from trusted source
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/jjp9pi...-firefox
  Already present!

Carol

- Gets a *different* **firefox.nix**
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/x64bxp...-firefox
  Builds it

Nix store

```
/nix/store
└── jjp9pi...-firefox
    ├── bin
    │   └── firefox
    └── lib
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        ├── libmozz.so
        └── ...
```

Sharing in Nix: Example

Alice

- Gets **firefox.nix** from trusted source
- Runs **nix-env -i firefox**
  Computes path:
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  Builds it

Bob

- Gets **firefox.nix** from trusted source
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/jjp9pi...-firefox
  Already present!

Carol

- Gets a *different* **firefox.nix**
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/x64bxp...-firefox
  Builds it

Nix store

```
/nix/store
├── jjp9pi...-firefox
│   ├── bin
│   │   └── firefox
│   └── lib
│       ├── libxpcom.so
│       ├── libmozz.so
│       └── ...
└── x64bxp...-firefox
    ├── bin
    │   └── firefox
    └── lib
        ├── libxpcom.so
        ├── libmozz.so
        └── ...
```

Attack method: interfere with local builds

Alice

- Gets **firefox.nix**
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/jjp9pi...-firefox
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Nix store

/nix/store
└── **...**

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- Gets **firefox.nix**
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/jjp9pi...-firefox
  Builds it

Bob

- Writes **evil.nix**
- Runs **nix-env -i evil**
  Computes path:
  /nix/store/01qr9w...-evil

Nix store

- **/nix/store**
  - **jjp9pi...-firefox**
    - **bin**
      - **firefox**
    - **lib**
      - **libxpcom.so**
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      - **...**

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  Computes path:
  /nix/store/jjp9pi...-firefox
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Nix store

```
/nix/store
└── jjp9pi...-firefox
    ├── bin
    │   └── firefox
    └── lib
        ├── libxpcom.so
        ├── libmozz.so
        └── ...
```

Bob

- Writes **evil.nix**
- Runs **nix-env -i evil**
  Computes path:
  /nix/store/01qr9w...-evil

Builder of **evil.nix**

```
#! /bin/sh
cp trojan-horse
  /nix/store/jjp9pi...-firefox/bin/firefox
```

Attack method: interfere with local builds

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- Runs **nix-env -i firefox**
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  Builds it

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```

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  Computes path:
  /nix/store/01qr9w...-evil
  Builds it

Nix store

/nix/store
- **jjp9pi...-firefox**
  - **bin**
  - **li**
    - **n.so**
    - **libmozz.so**
    - **...**
- **01qr9w...-evil**
  - **...**

Solution

Isolate builders

- Run each build under a unique user ID (**uid**)
- I.e., maintain a *pool of build users*:
  nix-build-1, **nix-build-2**, ...
- No two **uids** are used simultaneously
  - Kill all processes running under a **uid** before using that **uid**

Attack method: register fake substitutes

Alice

- Gets **firefox.nix**
- Pulls from **evil.org**
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/jjp9pi...-firefox
  Fake substitute is downloaded

Nix store

/nix/store
└── **...**

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- Runs **nix-env -i firefox**
  Computes path:
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  Fake substitute is downloaded

http://evil.org/

Contains Trojan horse substitute **jjp9pi...-firefox.nar.bz2**.

Nix store

/nix/store
└── **...**

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Nix store

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Contains Trojan horse substitute
jjp9pi...-firefox.nar.bz2.

Bob

- Gets **firefox.nix**
- Runs **nix-env -i firefox**
  Computes path:
  /nix/store/jjp9pi...-firefox
  Already present!
- Runs Firefox — 0wned!

Nix store

```
/nix/store
└── jjp9pi...-firefox
    ├── bin
    │   └──
    └── li
        ├── n.so
        ├── libmozz.so
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```

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Contains Trojan horse substitute
jjp9pi...-firefox.nar.bz2.

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  Computes path:
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  Already present!
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Nix store

```
/nix/store
└── jjp9pi...-firefox
    ├── bin
    │   └
    └── li
        ├            n.so
        ├── libmozz.so
        └── ...
```

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```
/nix/store
└── jjp9pi...-firefox
    ├── bin
    │   └──
    └── li
        ├──            n.so
        ├── libmozz.so
        └── ...
```

Fake substitutes

The problem

- We must *trust* that the substitute (*binary*) corresponds to the derivation (*source*) it claims to have been built from.
- The output path of a derivation (like **/nix/store/jjp9pi...-firefox**) is computed in advance.
- There can be only one **/nix/store/jjp9pi...-firefox** in the file system at any given time.
  - *Extensional model*: all contents are assumed to be interchangeable.
  - ... but they are not due to malicious substitutes.
- Thus the trust relation must be established globally, for all users.

Solution: A content-addressable Nix store

- *Content-addressibility*: the contents of an component in the store determine its file name
- Example:
  - If the contents of a component have hash **j153hbg6n21c...**
  - Then it will be stored in **/nix/store/j153hbg6n21c...**
- Result: if two components are equal, they are stored only once
- *Intensional model*: the hash in a path relates to the extensional behaviour of a component
- This model makes no assumptions that might not hold: content-addressability is a verifiable security invariant

Building in the content-addressable Nix store

Problem

Component store paths are no longer known in advance. But we need an output path!

Solution

- Use a temporary path with a random hash component, e.g. **\$out = /nix/store/0f9hrdwh3nd3...-firefox**
- Run the builder
- Compute the hash H over the output, e.g $H =$ **j153hbg6n21c...**
- Rename the temporary path to **/nix/store/**H-*name*, e.g. **/nix/store/j153hbg6n21c...-firefox**

Self-references

Problem

Components can contain references to their own path.

Example: /nix/store/0f9hrdwh3nd3...-firefox/bin/firefox

```
#! /bin/sh
...
moz_libdir=/nix/store/0f9hrdwh3nd3...-firefox/lib/...
...
dist_bin="$moz_libdir"
...
"$dist_bin/run-mozilla.sh" $script_args
    "$dist_bin/$MOZILLA_BIN" "$@"
```

Self-references (cont'd)

/nix/store/0f9hrdwh3nd3...-firefox/bin/firefox

```
...
0a 6d 6f 7a 5f 6c 69 62  64 69 72 3d 2f 6e 69 78  |.moz_libdir=/nix|
2f 73 74 6f 72 65 2f 30  66 39 68 72 64 77 68 33  |/store/0f9hrdwh3|
6e 64 33 6d 7a 35 63 71  63 6e 63 6c 79 35 62 77  |nd3mz5cqcncly5bw|
39 32 35 79 68 35 36 2d  66 69 72 65 66 6f 78 2f  |925yh56-firefox/|
6c 69 62 2f 66 69 72 65  66 6f 78 2d 31 2e 34 2e  |lib/firefox-1.4.|
31 0a 4d 52 45 5f 48 4f  4d 45 3d 2f 6e 69 78 2f  |1.MRE_HOME=/nix/|
73 74 6f 72 65 2f 30 66  39 68 72 64 77 68 33 6e  |store/0f9hrdwh3n|
64 33 6d 7a 35 63 71 63  6e 63 6c 79 35 62 77 39  |d3mz5cqcncly5bw9|
...
```

Solution

- Compute hashes *modulo self-references*:
  when computing the final hash, replace every occurence of the temporary hash by zeroes
- *Rewrite* occurences of the temporary hash to the final hash
  - Does this work? Yes!

Self-references (cont'd)

/nix/store/0f9hrdwh3nd3...-firefox/bin/firefox

```
...
0a 6d 6f 7a 5f 6c 69 62  64 69 72 3d 2f 6e 69 78  |.moz_libdir=/nix|
2f 73 74 6f 72 65 2f 00  00 00 00 00 00 00 00 00  |/store/000000000|
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |0000000000000000|
00 00 00 00 00 00 00 2d  66 69 72 65 66 6f 78 2f  |0000000-firefox/|
6c 69 62 2f 66 69 72 65  66 6f 78 2d 31 2e 34 2e  |lib/firefox-1.4.|
31 0a 4d 52 45 5f 48 4f  4d 45 3d 2f 6e 69 78 2f  |1.MRE_HOME=/nix/|
73 74 6f 72 65 2f 30 66  39 68 72 64 77 68 33 6e  |store/0f9hrdwh3n|
64 33 6d 7a 35 63 71 63  6e 63 6c 79 35 62 77 39  |d3mz5cqcncly5bw9|
...
```

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/nix/store/0f9hrdwh3nd3...-firefox/bin/firefox

```
...
0a 6d 6f 7a 5f 6c 69 62  64 69 72 3d 2f 6e 69 78  |.moz_libdir=/nix|
2f 73 74 6f 72 65 2f 6a  31 35 33 68 62 67 36 6e  |/store/j153hbg6n|
32 31 63 62 33 79 6d 79  6b 62 79 64 70 78 36 6b  |21cb3ymykbydpx6k|
32 63 39 64 78 70 34 2d  66 69 72 65 66 6f 78 2f  |2c9dxp4-firefox/|
6c 69 62 2f 66 69 72 65  66 6f 78 2d 31 2e 34 2e  |lib/firefox-1.4.|
31 0a 4d 52 45 5f 48 4f  4d 45 3d 2f 6e 69 78 2f  |1.MRE_HOME=/nix/|
73 74 6f 72 65 2f 30 66  39 68 72 64 77 68 33 6e  |store/0f9hrdwh3n|
64 33 6d 7a 35 63 71 63  6e 63 6c 79 35 62 77 39  |d3mz5cqcncly5bw9|
...
```

Solution

- Compute hashes *modulo self-references*:
  when computing the final hash, replace every occurence of the temporary hash by zeroes
- *Rewrite* occurences of the temporary hash to the final hash
  - Does this work? Yes!

Self-references (cont'd)

/nix/store/0f9hrdwh3nd3...-firefox/bin/firefox

```
...
0a 6d 6f 7a 5f 6c 69 62  64 69 72 3d 2f 6e 69 78  |.moz_libdir=/nix|
2f 73 74 6f 72 65 2f 6a  31 35 33 68 62 67 36 6e  |/store/j153hbg6n|
32 31 63 62 33 79 6d 79  6b 62 79 64 70 78 36 6b  |21cb3ymykbydpx6k|
32 63 39 64 78 70 34 2d  66 69 72 65 66 6f 78 2f  |2c9dxp4-firefox/|
6c 69 62 2f 66 69 72 65  66 6f 78 2d 31 2e 34 2e  |lib/firefox-1.4.|
31 0a 4d 52 45 5f 48 4f  4d 45 3d 2f 6e 69 78 2f  |1.MRE_HOME=/nix/|
73 74 6f 72 65 2f 30 66  39 68 72 64 77 68 33 6e  |store/0f9hrdwh3n|
64 33 6d 7a 35 63 71 63  6e 63 6c 79 35 62 77 39  |d3mz5cqcncly5bw9|
...
```

Solution

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  - Does this work? Yes!

So how does this help?

- A single derivation can now have different outputs.
- In particular substitutes can now be *user-specific*.

Example

Alice

- Gets **firefox.nix**
- Pulls from **evil.org**
- Runs **nix-env -i firefox**
  Selects substitute:
  /nix/store/78k8w842kl8p...-firefox
  Fake substitute is downloaded

Nix store

/nix/store
└── **...**

Example

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/nix/store
└── **...**

http://evil.org/

Contains Trojan horse substitute **78k8w842kl8p...-firefox.nar.bz2**.

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Nix store

/nix/store
└── **78k8w842kl8p...-firefox**
    ├── **bin**
    │   └
    └── **li**
        ├ **.so**
        └── **...**

http://evil.org/

Contains Trojan horse substitute
78k8w842kl8p...-firefox.nar.bz2.

Example

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Contains Trojan horse substitute
78k8w842kl8p...-firefox.nar.bz2.

Bob

- Gets **firefox.nix**
- Pulls from **good.org**
- Runs **nix-env -i firefox**
  Selects substitute:
  /nix/store/j153hbg6n21c...-firefox
  Good substitute is downloaded

Nix store

```
/nix/store
└── 78k8w842kl8p...-firefox
    ├── bin
    │   └
    └── li
        ├            .so
        └── ...
```

Example

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- Gets **firefox.nix**
- Pulls from **evil.org**
- Runs **nix-env -i firefox**
  Selects substitute:
  /nix/store/78k8w842kl8p...-firefox
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Nix store

/nix/store
└── **78k8w842kl8p...-firefox**
    ├── **bin**
    │   └
    └── **li**
        ├ **.so**
        └── **...**

http://good.org/

Contains bona fide substitute
j153hbg6n21c...-firefox.nar.bz2.

Example

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- Gets **firefox.nix**
- Pulls from **evil.org**
- Runs **nix-env -i firefox**
  Selects substitute:
  /nix/store/78k8w842kl8p...-firefox
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Contains Trojan horse substitute
78k8w842kl8p...-firefox.nar.bz2.

Bob

- Gets **firefox.nix**
- Pulls from **good.org**
- Runs **nix-env -i firefox**
  Selects substitute:
  /nix/store/j153hbg6n21c...-firefox
  Good substitute is downloaded

Nix store

```
/nix/store
├── 78k8w842kl8p...-firefox
│   ├── bin
│   │   └──
│   └── li
│       ├──             .so
│       └── ...
└── j153hbg6n21c...-firefox
    ├── bin
    │   └── firefox
    └── lib
        ├── libmozz.so
        └── ...
```

http://good.org/

Contains bona fide substitute
j153hbg6n21c...-firefox.nar.bz2.

Implementation aspect: Equivalence classes

- How do we know which substitute to use for **firefox.nix**?
- By computing the *output equivalence class*: a cryptographic hash of derivation attributes
  - This is how the component's path was computed in the extensional model
- Equivalence class + username is the key of the substitute mapping

Example

- Equivalence class for **firefox.nix** is **/nix/store/jjp9pi...-firefox**
- **substitute**[(**/nix/store/jjp9pi...-firefox**, **alice**)] =
  (**/nix/store/78k8w842kl8p...-firefox**, ...*url*...)
  substitute[(**/nix/store/jjp9pi...-firefox**, **bob**)] =
  (**/nix/store/j153hbg6n21c...-firefox**, ...*url*...)

Implementation aspect: Equivalence classes

- How do we know which substitute to use for **firefox.nix**?
- By computing the *output equivalence class*: a cryptographic hash of derivation attributes
  - This is how the component's path was computed in the extensional model
- Equivalence class + username is the key of the substitute mapping

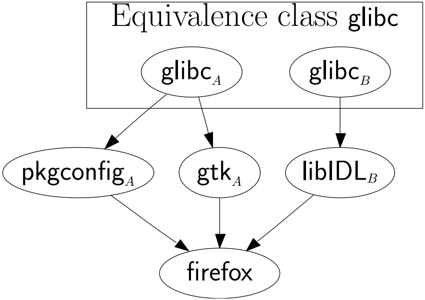
Example

- Equivalence class for **firefox.nix** is **/nix/store/jjp9pi...-firefox**
- **substitute**[(**/nix/store/jjp9pi...-firefox**, **alice**)] =
  (**/nix/store/78k8w842kl8p...-firefox**, *...url...*)
  substitute[(**/nix/store/jjp9pi...-firefox**, **bob**)] =
  (**/nix/store/j153hbg6n21c...-firefox**, *...url...*)

Equivalence class collisions

Problem

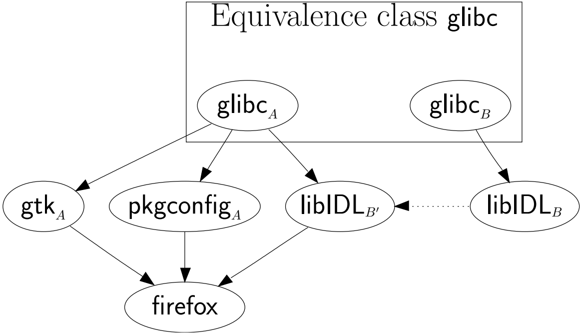
When building, the inputs can contain multiple paths from the *same equivalence class*.



Equivalence class collisions (cont'd)

Solution

Rewrite *one* path from each equivalence class, then *rewrite* references.



Conclusions

- Main contribution: a package manage system that allows any user to install software, with secure sharing between untrusted users
- Content-addressable component stores allow binary components to be shared safely
  - Hash rewriting is required to support self-referential components
- It is possible to share locally built components safely
- Transparent source/binary deployment can be done safely and selectively between mutually trusted users