Livestream: https://www.youtube.com/live/NyQced4oJVM?si=ISHeNTi8bI6kMvxC

Understanding Dispatching Approaches in the Scientific Python Ecosystem

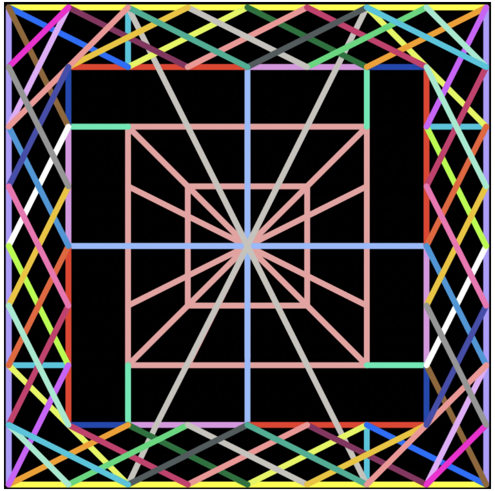
- By Aditi Juneja and Sebastian Berg

Aditi Juneja (@Schefflera-Arboricola)

- **Grants/programs**: Google Summer of Code 2024, NumFOCUS's Small Development Grant (R3, 2024), CZI*

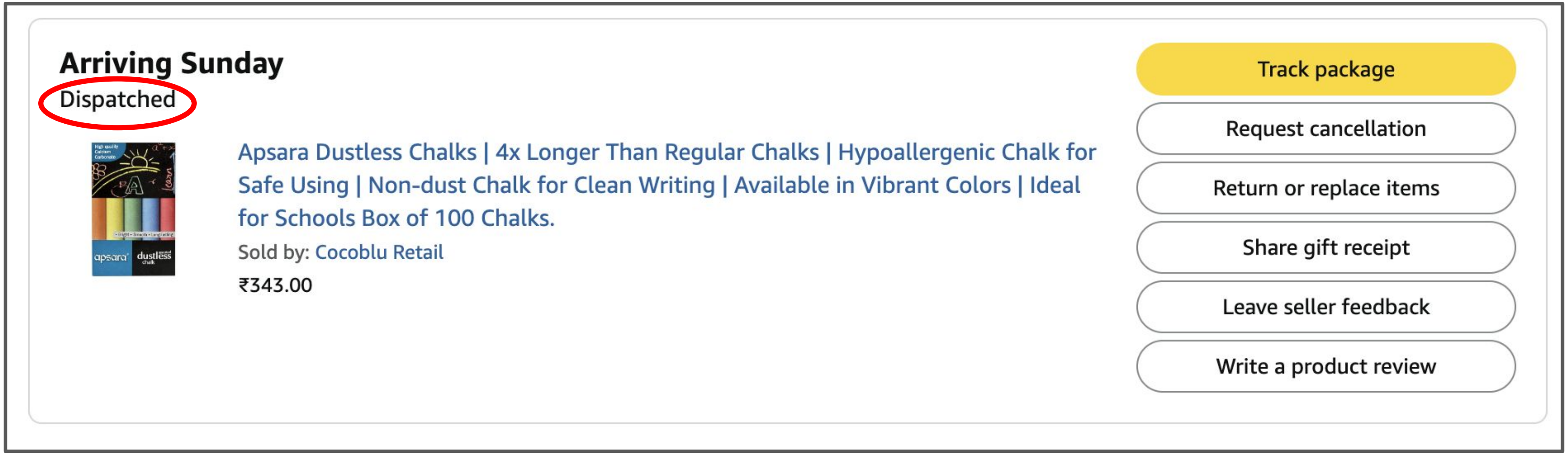
- **Open source projects/contributions**: nx-parallel, NetworkX (Core developer), scikit-image (dispatching), other small small contributions in various scientific Python projects!

- **Communities and Volunteering roles**: SciPy India (core-organiser), GSoC 2025 mentor (NetworkX), SciPy 2025 (proceedings paper reviewer), Scientific Python (maintainer - dispatch team), IndiaFOSS 2025 ("FOSS in Science" devroom manager), PyDelhi (reviewer), PyData Global 2024 (reviewer), PyCon US 2025 (proposal mentor)



Find work blogs, talk slides, CV, etc. at https://github.com/Schefflera-Arboricola/blogs

Dispatching??



Arriving Sunday

Dispatched

Apsara Dustless Chalks | 4x Longer Than Regular Chalks | Hypoallergenic Chalk for Safe Using | Non-dust Chalk for Clean Writing | Available in Vibrant Colors | Ideal for Schools Box of 100 Chalks.

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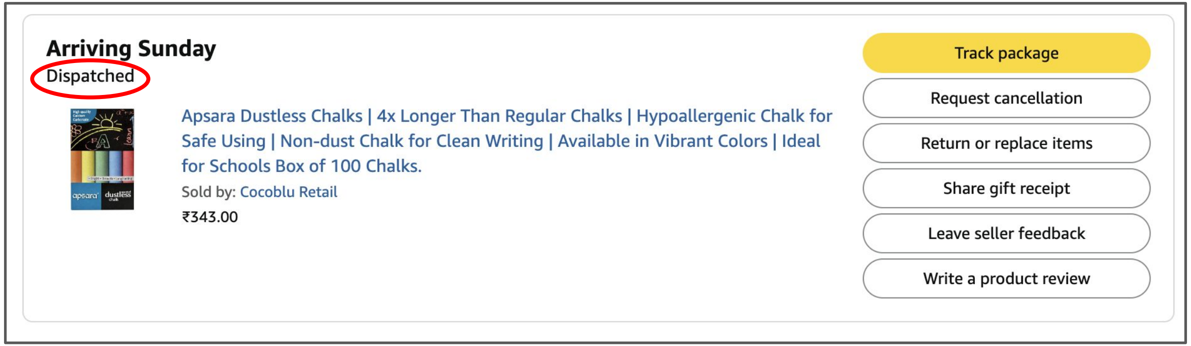
Dispatching– in general



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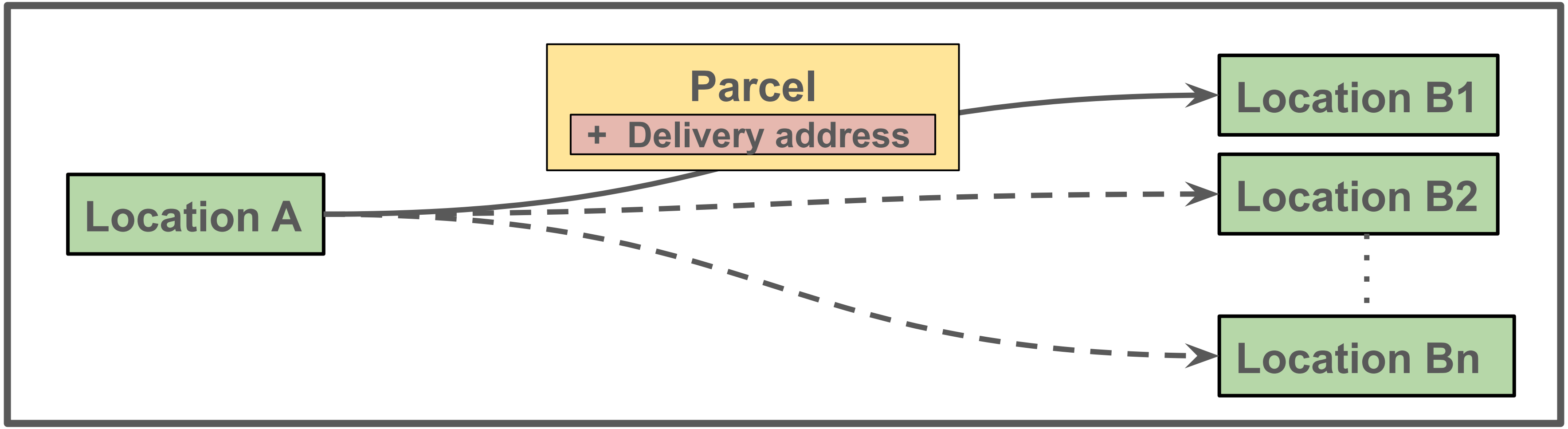

Dispatching – in programming

“In computer science, **dynamic dispatch** is the process of selecting which implementation of a polymorphic operation (method or function) to call at **run time.**”

Ref. https://en.wikipedia.org/wiki/Dynamic_dispatch

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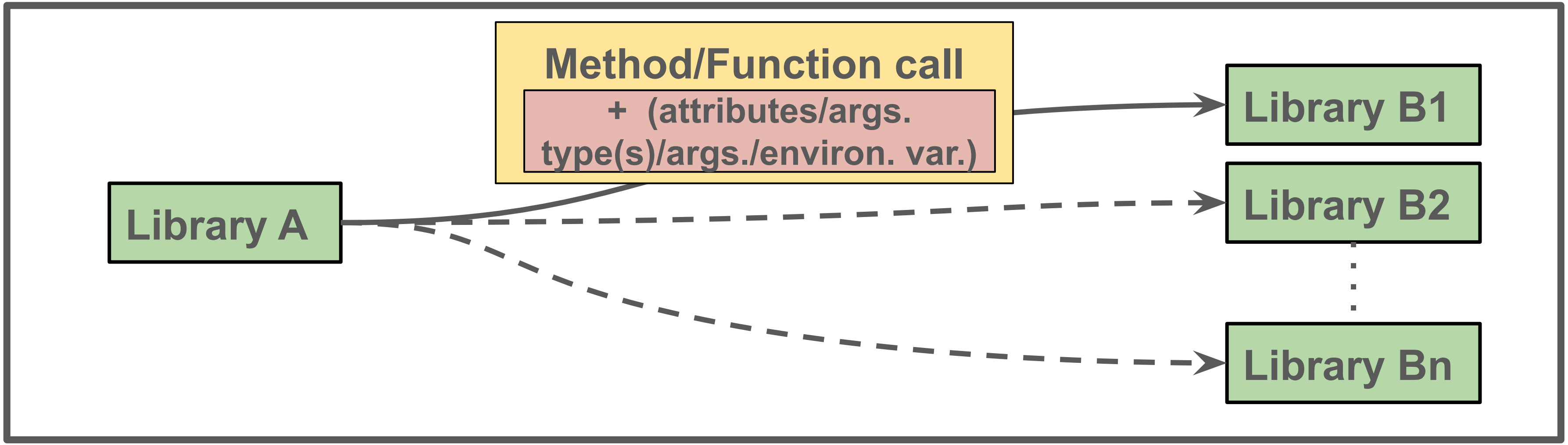

But.. Why would anyone want to dispatch?

But.. Why would anyone want to dispatch?

Improve Performance

Type Compatibility

Enable different workflows

But.. Why would anyone want to dispatch?

And how exactly is it done?

Example

What does dispatching mean here?

library_A

```
def add(x, y, z):
    return x + y + z
```

Importing and Calling (hard-coded)

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library_A

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
        import library_B1 as libB1
        z = float(z)
        return libB1.mod1.add(x, y, z)
    elif libB == “library_B2” :
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    ...
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```

Importing and Calling (hard-coded)

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```

Can we make this more general?

Importing and Calling (hard-coded)

Inside `library_A`

```
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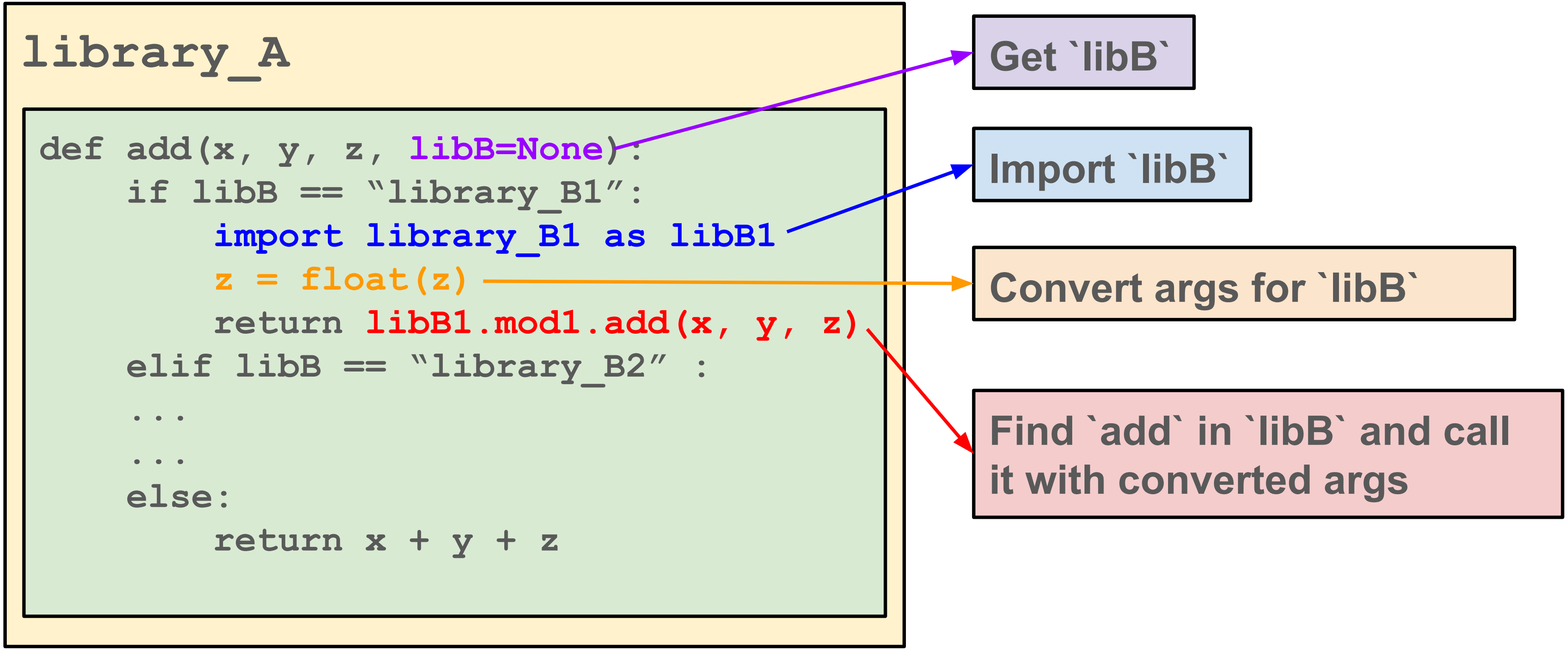
Steps involved

Steps involved



library_A

```
def add(x, y, z, libB=None):
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        import library_B1 as libB1
        z = float(z)
        return libB1.mod1.add(x, y, z)
    elif libB == “library_B2” :
    ...
    ...
    else:
        return x + y + z
```

Get `libB`

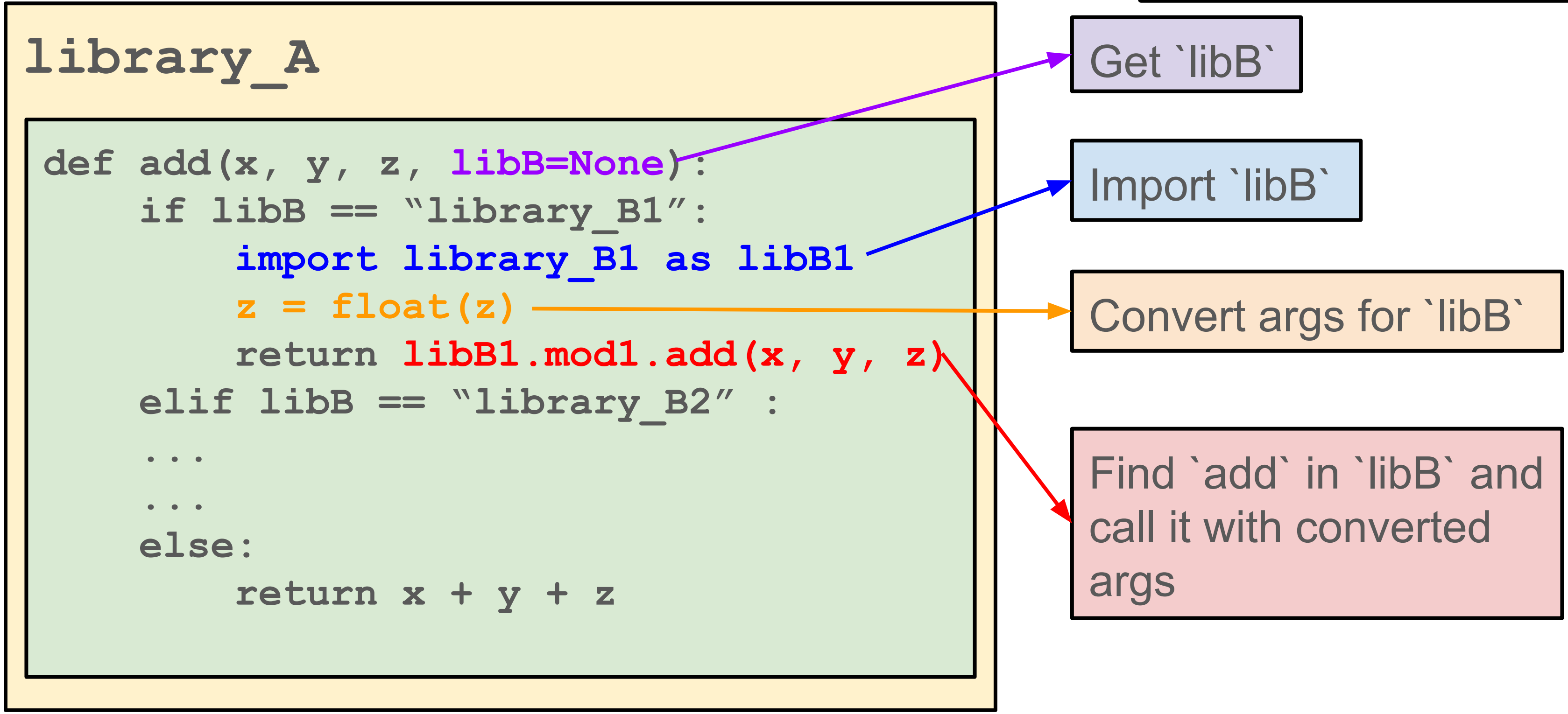
Import `libB`

Convert args for `libB`

Find `add` in `libB` and call it with converted args

Steps involved

… maybe we can delegate some of these steps to `libB`...



library_A

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def add(x, y, z, libB=None):
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    ...
    ...
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```

Get `libB`

Import `libB`

Convert args for `libB`

Find `add` in `libB` and call it with converted args

Step 4: Find `add` in `libB` and call it

Inside `library_A`

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
        import library_B1 as libB1
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        return libB1.mod1.add(x, y, z)
    elif libB == “library_B2” :
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    else:
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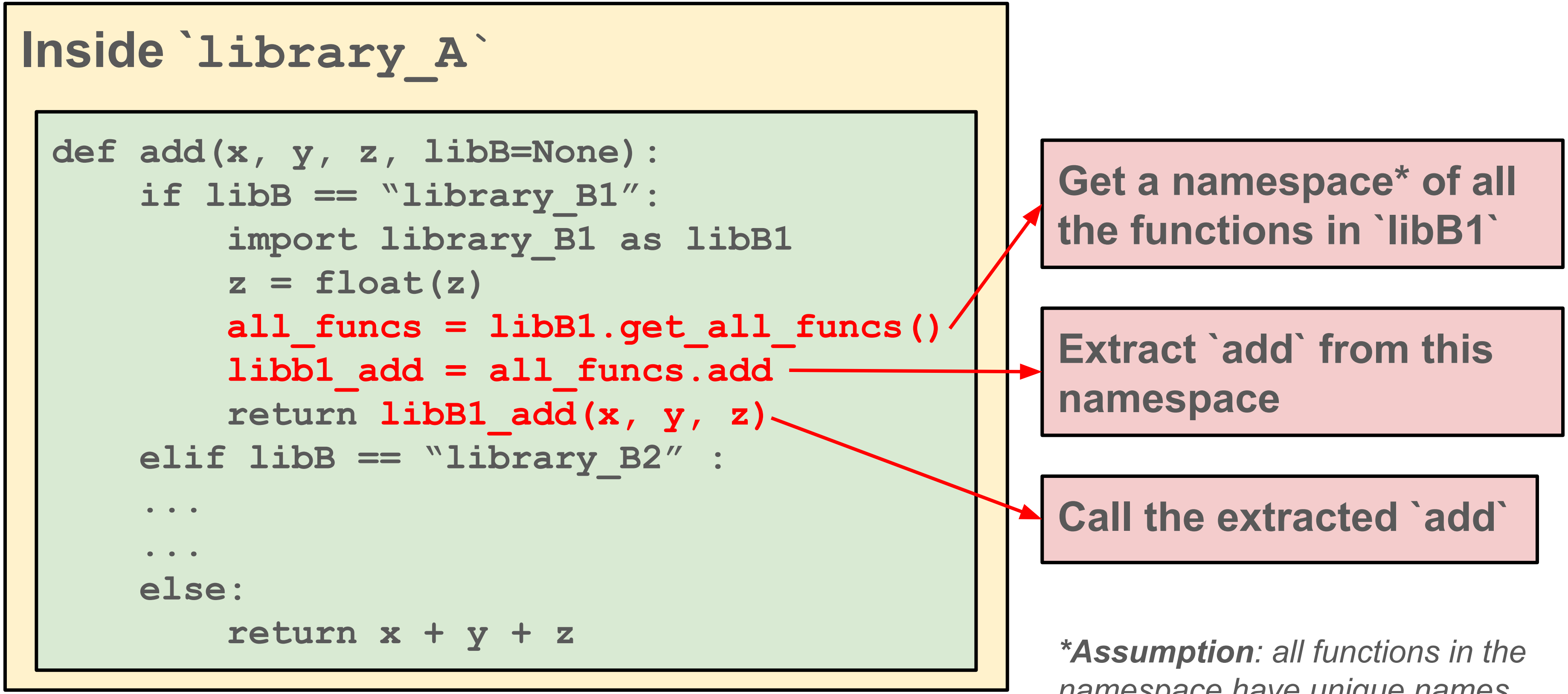
```

Find `add` in `libB` and call it with converted args

Step 4: Find `add` in `libB` and call it



Inside `library_A`

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
        import library_B1 as libB1
        z = float(z)
        all_funcs = libB1.get_all_funcs()
        libb1_add = all_funcs.add
        return libB1_add(x, y, z)
    elif libB == “library_B2” :
    ...
    ...
    else:
        return x + y + z
```

Get a namespace* of all the functions in `libB1`

Extract `add` from this namespace

Call the extracted `add`

*****Assumption****: all functions in the namespace have unique names*

Step 3: convert args for `add` in `libB`

Inside `library_A`

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
        import library_B1 as libB1
        z = float(z)
        all_funcs = libB1.get_all_funcs()
        libb1_add = all_funcs.add
        return libB1_add(x, y, z)
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    else:
        return x + y + z
```

Convert args for `libB`

Step 3: convert args for `add` in `libB`

Inside `library_A`

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
        import library_B1 as libB1
        x, y, z = libb1.convert_args(add, x, y, z)
        all_funcs = libB1.get_all_funcs()
        libb1_add = all_funcs.add
        return libB1_add(x, y, z)
    elif libB == “library_B2” :
    ...
    ...
    else:
        return x + y + z
```

Convert function in `libB`

Step 2: import `libB`

Inside `library_A`

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
        import library_B1 as libB1
        x, y, z = libb1.convert_args(add, x, y, z)
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        return libB1_add(x, y, z)
    elif libB == “library_B2” :
    ...
    ...
    else:
        return x + y + z
```

Import `libB`

Step 2: import `libB`

Inside `library_A`

```
def add(x, y, z, libB=None):
    lib = __import__(libB)
    if libB == “library_B1”:
        x, y, z = lib.convert_args(add, x, y, z)
        all_funcs = lib.get_all_funcs()
        lib_add = all_funcs.add
        return lib_add(x, y, z)
    elif libB == “library_B2” :
    ...
    ...
    else:
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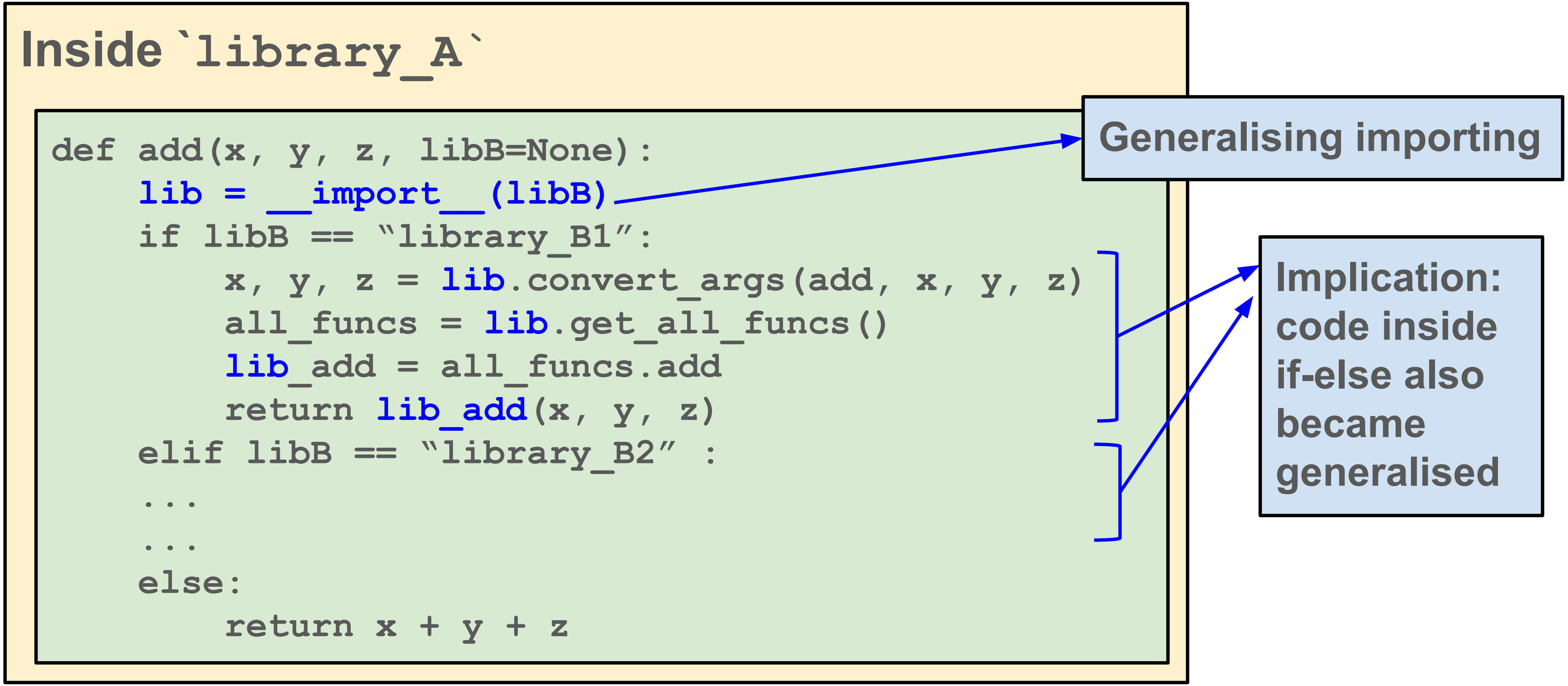
```

Generalising importing

Step 2: import `libB`



Inside `library_A`

```
def add(x, y, z, libB=None):
    lib = __import__(libB)
    if libB == “library_B1”:
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        all_funcs = lib.get_all_funcs()
        lib_add = all_funcs.add
        return lib_add(x, y, z)
    elif libB == “library_B2” :
    ...
    ...
    else:
        return x + y + z
```

Generalising importing

Implication: code inside if-else also became generalised

Step 2: import `libB`

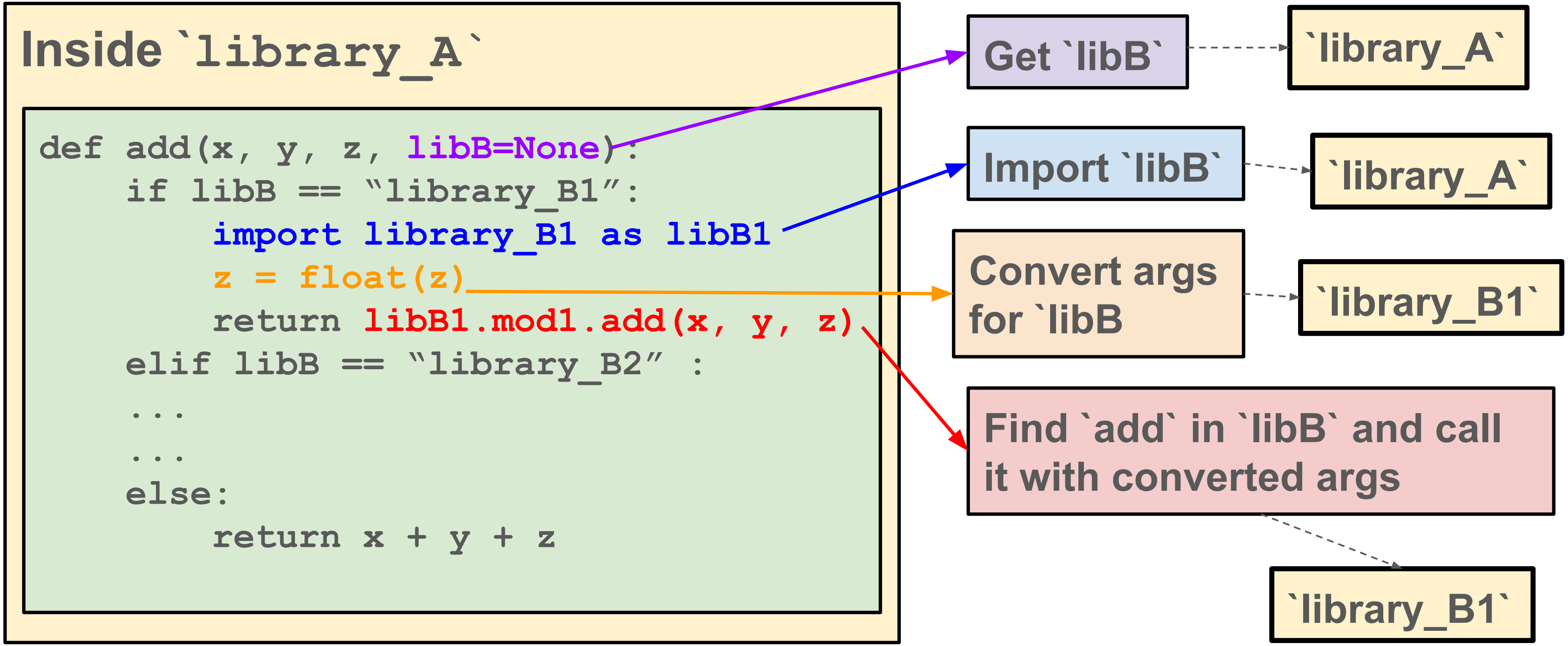
Inside `library_A`

```
def add(x, y, z, libB=None):
    if libB != None:
        lib = __import__(libB)
        x, y, z = lib.convert_args(add, x, y, z)
        all_funcs = lib.get_all_funcs()
        lib_add = all_funcs.add
        return lib_add(x, y, z)
    else:
        return x + y + z
```

Generalising importing

Getting rid of `if-else` conditions

Dispatching



Inside `library_A`

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
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    ...
    ...
    else:
        return x + y + z
```

Get `libB` → `library_A`

Import `libB` → `library_A`

Convert args for `libB → `library_B1`

Find `add` in `libB` and call it with converted args → `library_B1`

Dispatching

Inside `library_A` (import and call)

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
        import library_B1 as libB1
        z = float(z)
        return libB1.mod1.add(x, y, z)
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Inside `library_A` (dispatching)

```
def add(x, y, z, libB=None):
    if libB != None:
        lib = __import__(libB)
        x, y, z = lib.convert_args(add,
x, y, z)
        all_funcs = lib.get_all_funcs()
        lib_add = all_funcs.add
        return lib_add(x, y, z)
    else:
        return x + y + z
```

Dispatching

Can we do something more here?

Inside `library_A` (import and call)

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
        import library_B1 as libB1
        z = float(z)
        return libB1.mod1.add(x, y, z)
    elif libB == “library_B2” :
    ...
    ...
    else:
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```

Inside `library_A` (dispatching)

```
def add(x, y, z, libB=None):
    if libB != None:
        lib = __import__(libB)
        x, y, z = lib.convert_args(add,
x, y, z)
        all_funcs = lib.get_all_funcs()
        lib_add = all_funcs.add
        return lib_add(x, y, z)
    else:
        return x + y + z
```

Dispatching

Yes! use decorator.
Generalising for all functions

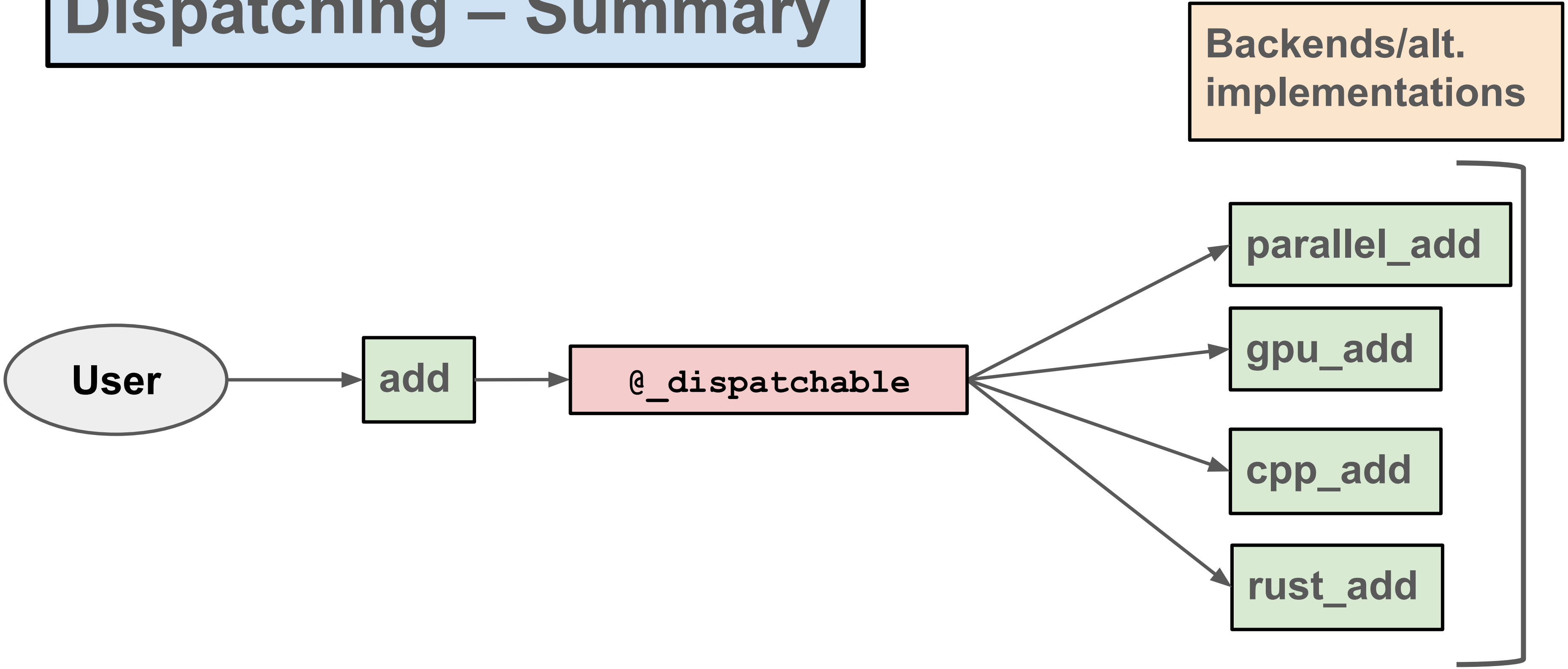
Inside `library_A`

```
@_dispatchable
def add(x, y, z):
      return x + y + z
```

```
def _dispatchable():
    @functools.wraps(func)
    def wrapper(*args, **kwargs):
        # check for libB kwarg in the function signature
        libB = kwargs.get("libB")
        try:
            lib = __import__(libB)
            args = lib.convert_args(func, *args, **kwargs)
            all_funcs = lib.get_all_funcs()
            lib_func = all_funcs.func
            return lib_func(args)
         except ImportError:
             return func(*args, **kwargs)
     return wrapper
```

**there are other ways of dispatching as well.*

Dispatching – Summary



How is dispatching done in real projects?

Some projects we’ll discuss:

- Graphs: **NetworkX**

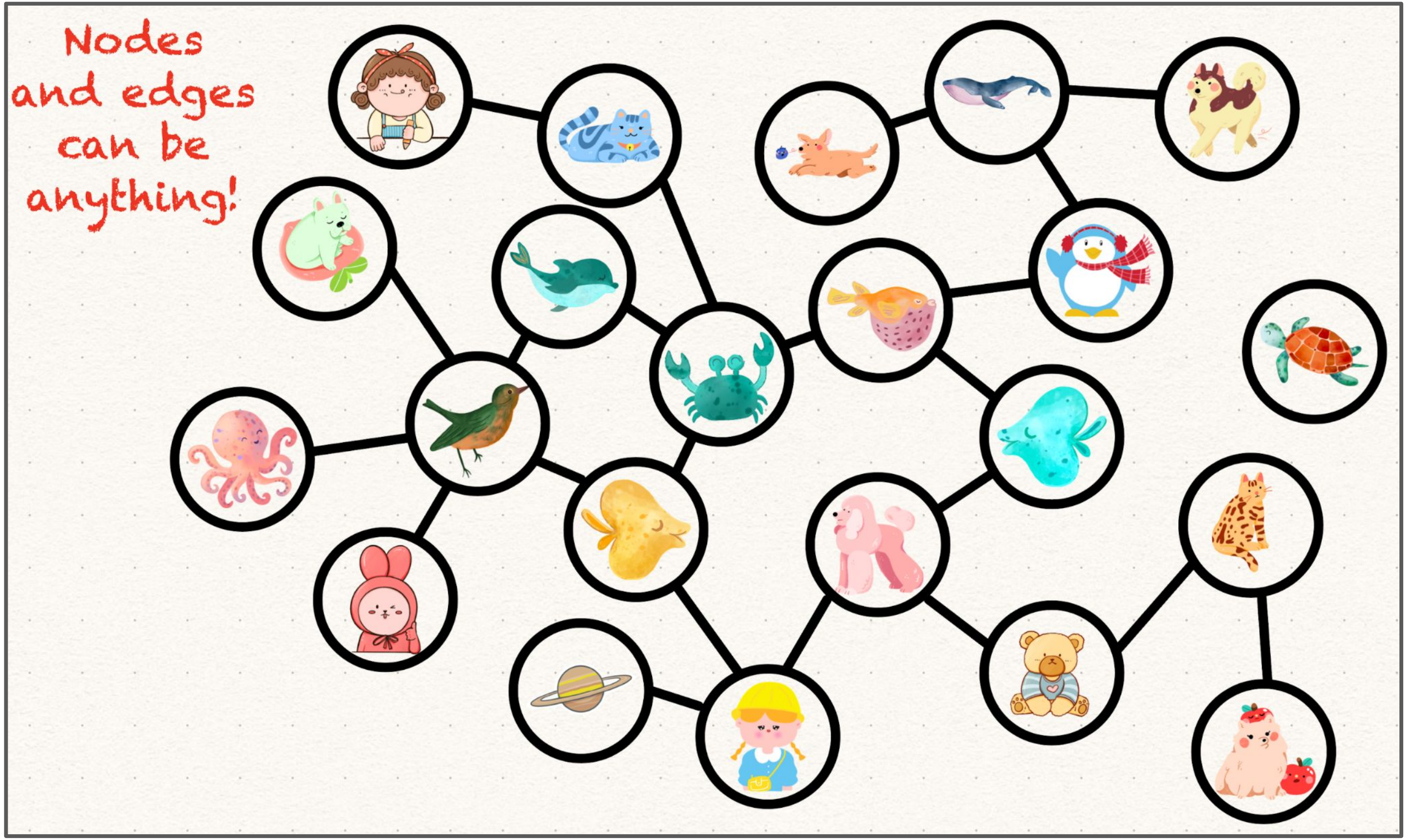
- Arrays:
    - **NumPy** : __array_function__
    - Array API standards→ Pradyot’s talk!

- **Scikit-image** and **spatch**

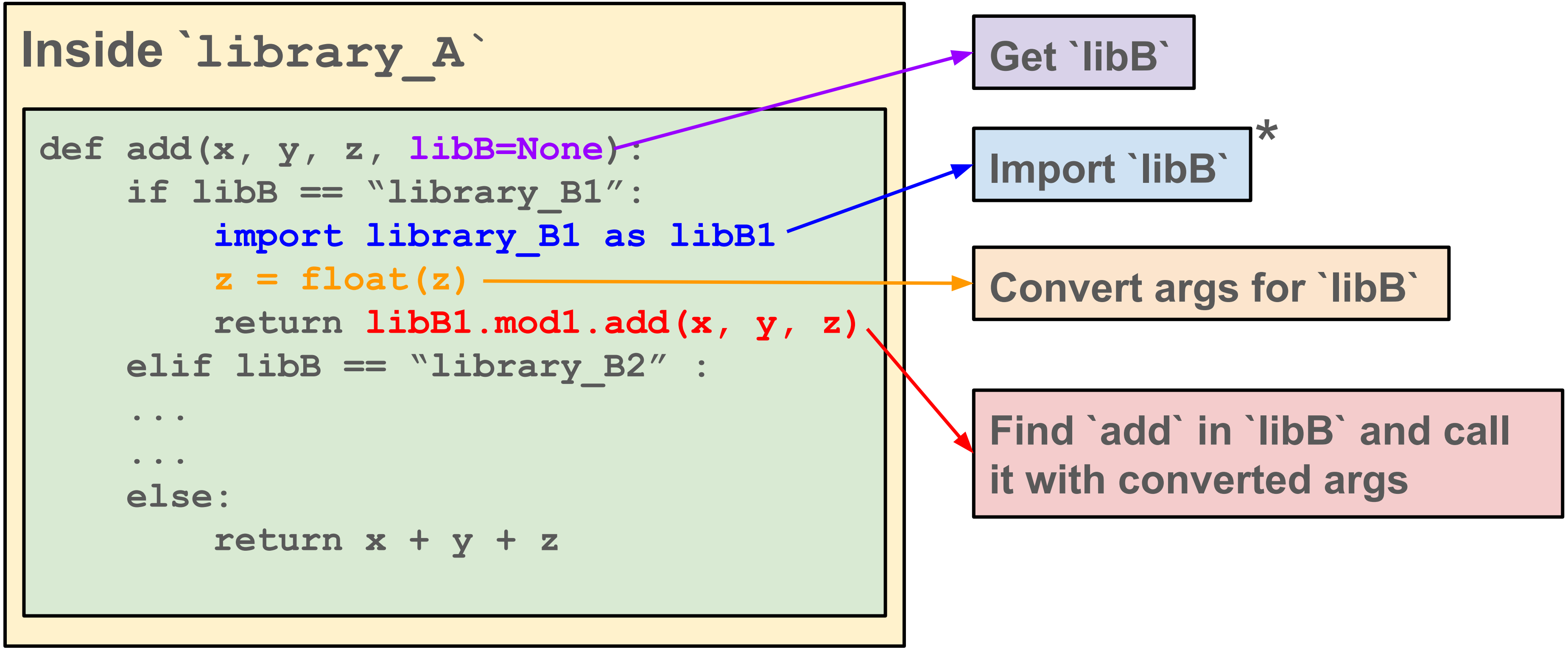
Dispatching in NetworkX for Graphs

What is NetworkX?

NetworkX is a graph analysis library



Steps involved in dispatching



Inside `library_A`

```
def add(x, y, z, libB=None):
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    elif libB == "library_B2" :
    ...
    ...
    else:
        return x + y + z
```

Get `libB`

Import `libB`*

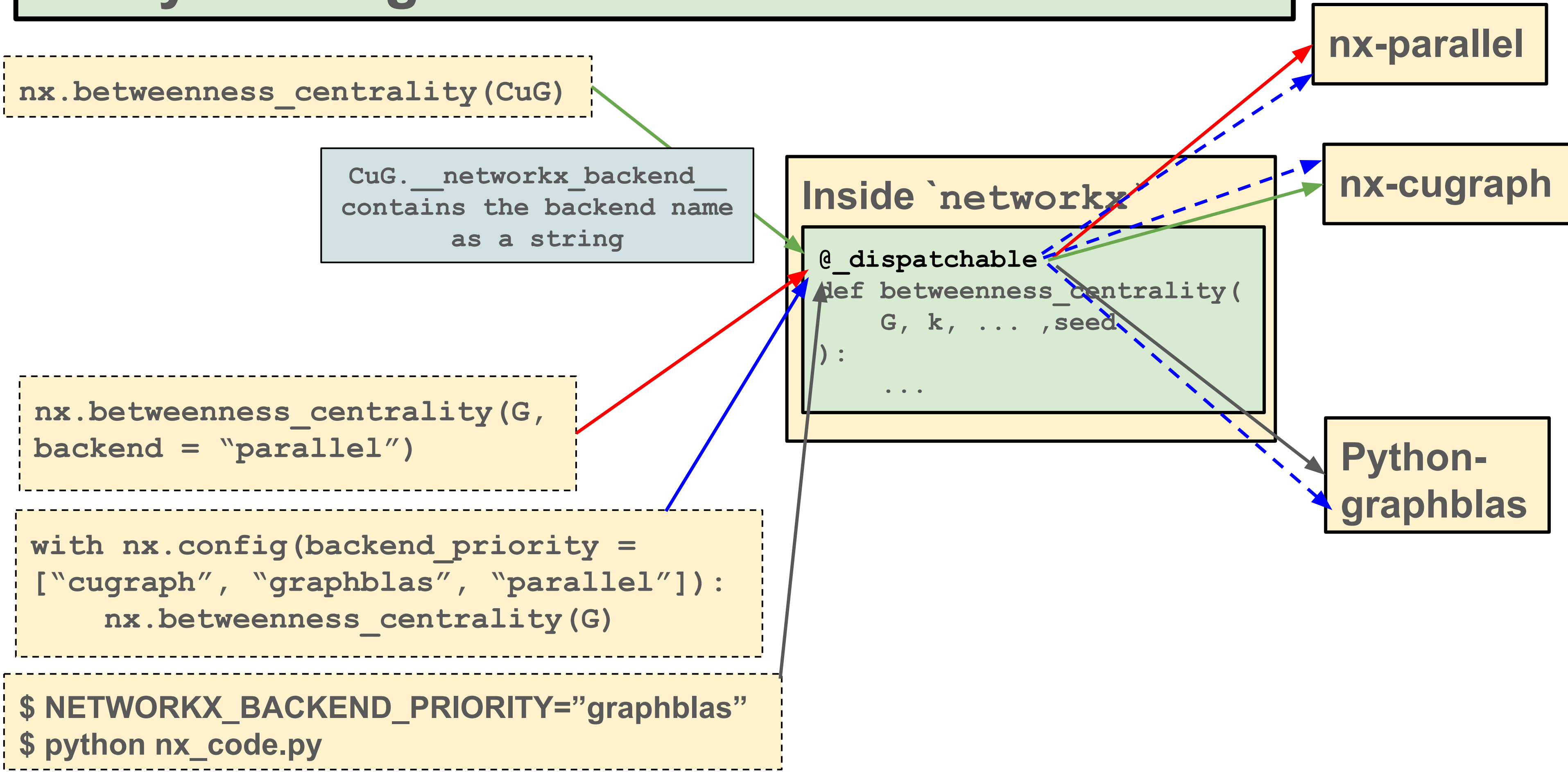
Convert args for `libB`

Find `add` in `libB` and call it with converted args

Getting the backend name in NetworkX

Demo:
https://colab.research.google.com/drive/16bUxGvBoBAg1dBRc6yfjxixlo7DocM8s?usp=sharing

4 ways of to get backend name in NetworkX



```
nx.betweenness_centrality(CuG)
```

```
CuG.__networkx_backend__
contains the backend name
as a string
```

```
nx.betweenness_centrality(G,
backend = “parallel”)
```

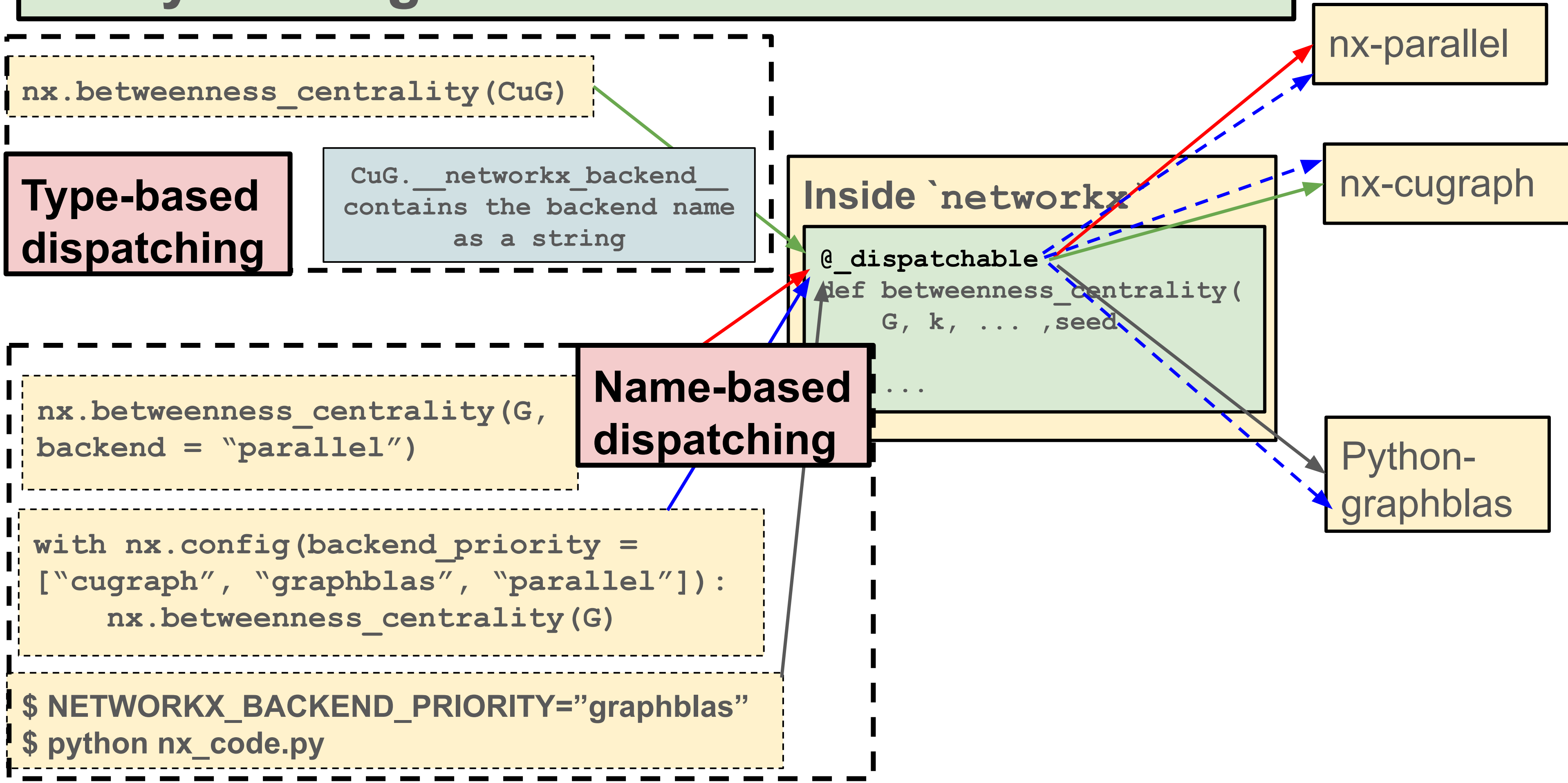
```
with nx.config(backend_priority =
[“cugraph”, “graphblas”, “parallel”]):
    nx.betweenness_centrality(G)
```

```
$ NETWORKX_BACKEND_PRIORITY=”graphblas”
$ python nx_code.py
```

Inside `networkx`

```
@_dispatchable
def betweenness_centrality(
    G, k, ... ,seed
):
    ...
```

4 ways of to get backend name in NetworkX



Type-based dispatching

```
nx.betweenness_centrality(CuG)
```

CuG.__networkx_backend__ contains the backend name as a string

Name-based dispatching

```
nx.betweenness_centrality(G,
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```

```
with nx.config(backend_priority =
["cugraph", "graphblas", "parallel"]):
    nx.betweenness_centrality(G)
```

```
$ NETWORKX_BACKEND_PRIORITY="graphblas"
$ python nx_code.py
```

Inside `networkx`

```
@_dispatchable
def betweenness_centrality(
    G, k, ... ,seed
...
```

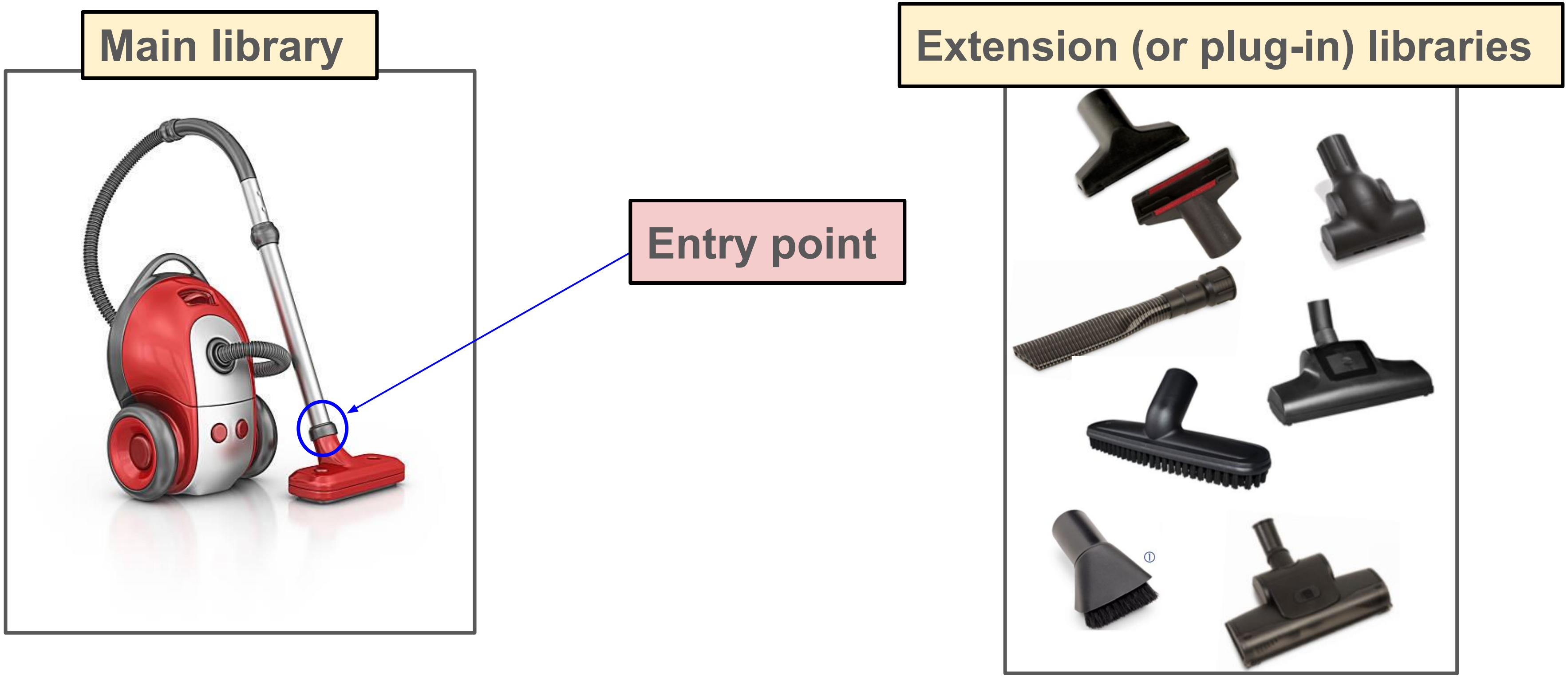
Getting the backend implementation

Python entry-points to get all the installed backends…

… and their metadata – supported functions and convert functions.

What are entry-points?

Entry-points are used **to extend a functionality** of a library.



Main library

Entry point

Extension (or plug-in) libraries

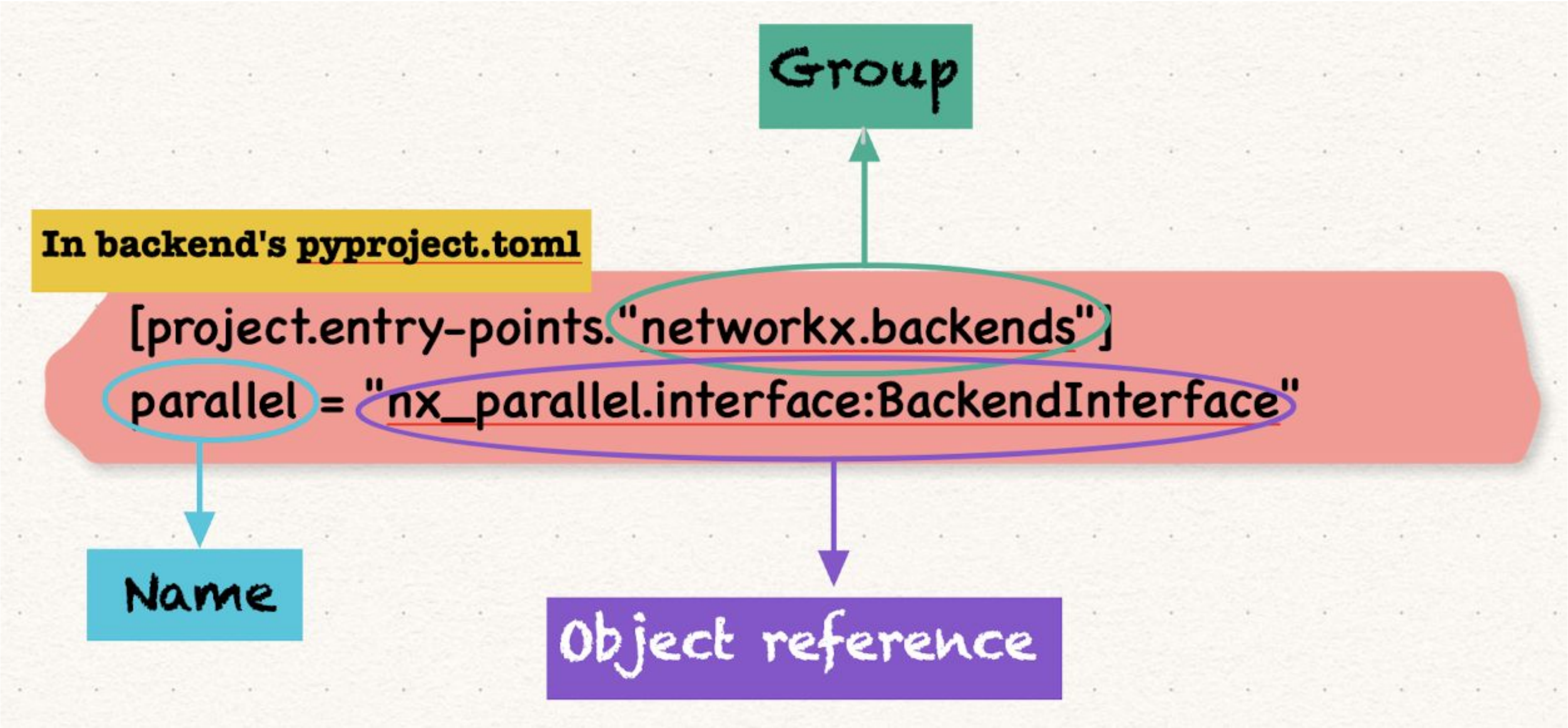
Dispatching with entry-points is exploiting entry-points to the max–

i.e. change the whole machinery inside the vacuum cleaner (main library's implementation)– and just keep the outside red UI-plastic-buttons frame (user-API).

In NetworkX

```
>>> from importlib.metadata import entry_points
>>> entry_points(group="networkx.backends")
(
    EntryPoint(
        name="parallel",
        value="nx_parallel.interface:BackendInterface",
        group="networkx.backends",
    ),
    ...
    ...
    EntryPoint(
        name="cugraph",
        value="nx_cugraph.interface:BackendInterface",
        group="networkx.backends",
    ),
)
```

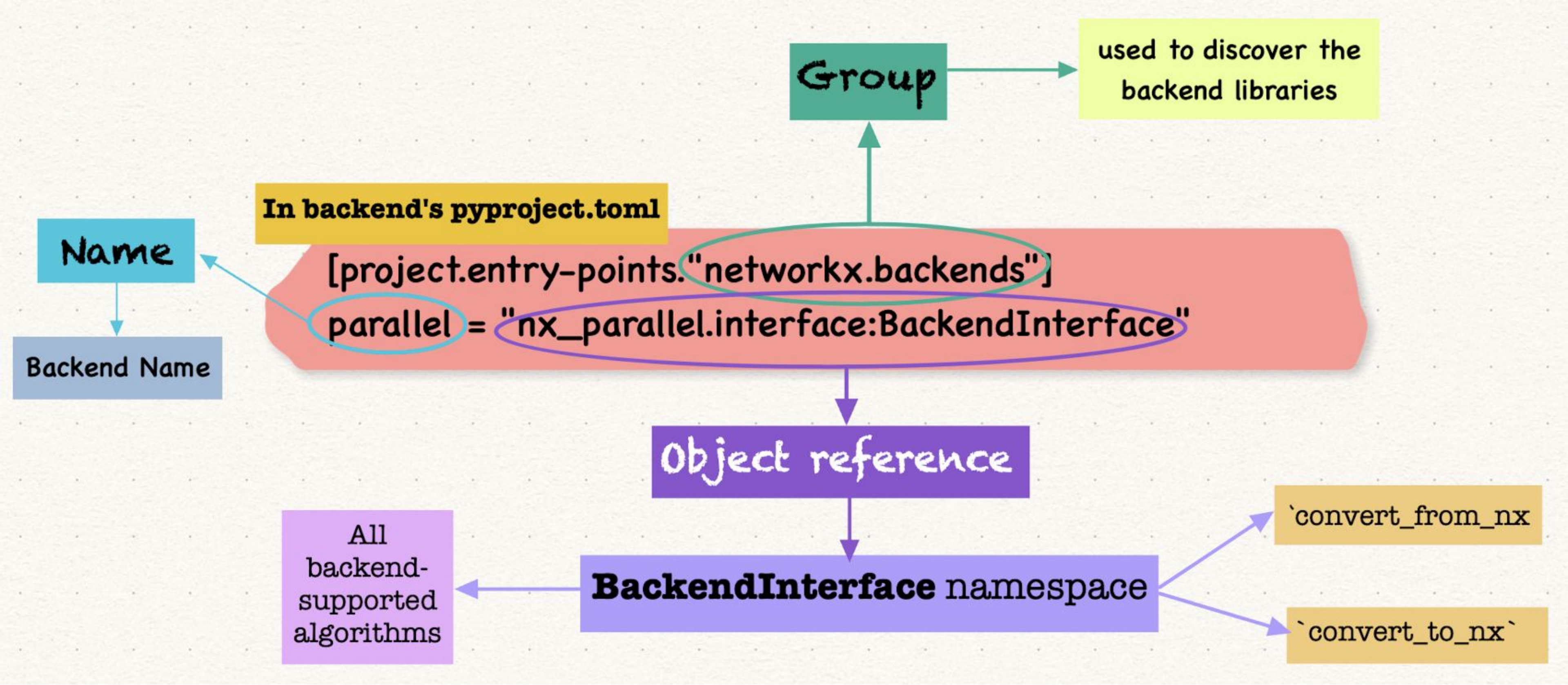
Inside nx-parallel backend



In backend's pyproject.toml

```
[project.entry-points."networkx.backends"]
parallel = "nx_parallel.interface:BackendInterface"
```

Inside nx-parallel backend



In backend's pyproject.toml

```
[project.entry-points."networkx.backends"]
parallel = "nx_parallel.interface:BackendInterface"
```

Group
used to discover the backend libraries
Name
Backend Name
Object reference
All backend-supported algorithms
BackendInterface namespace
`convert_from_nx
`convert_to_nx`

ref. https://packaging.python.org/en/latest/specifications/entry-points/

Other features of NetworkX dispatching (if time permits)

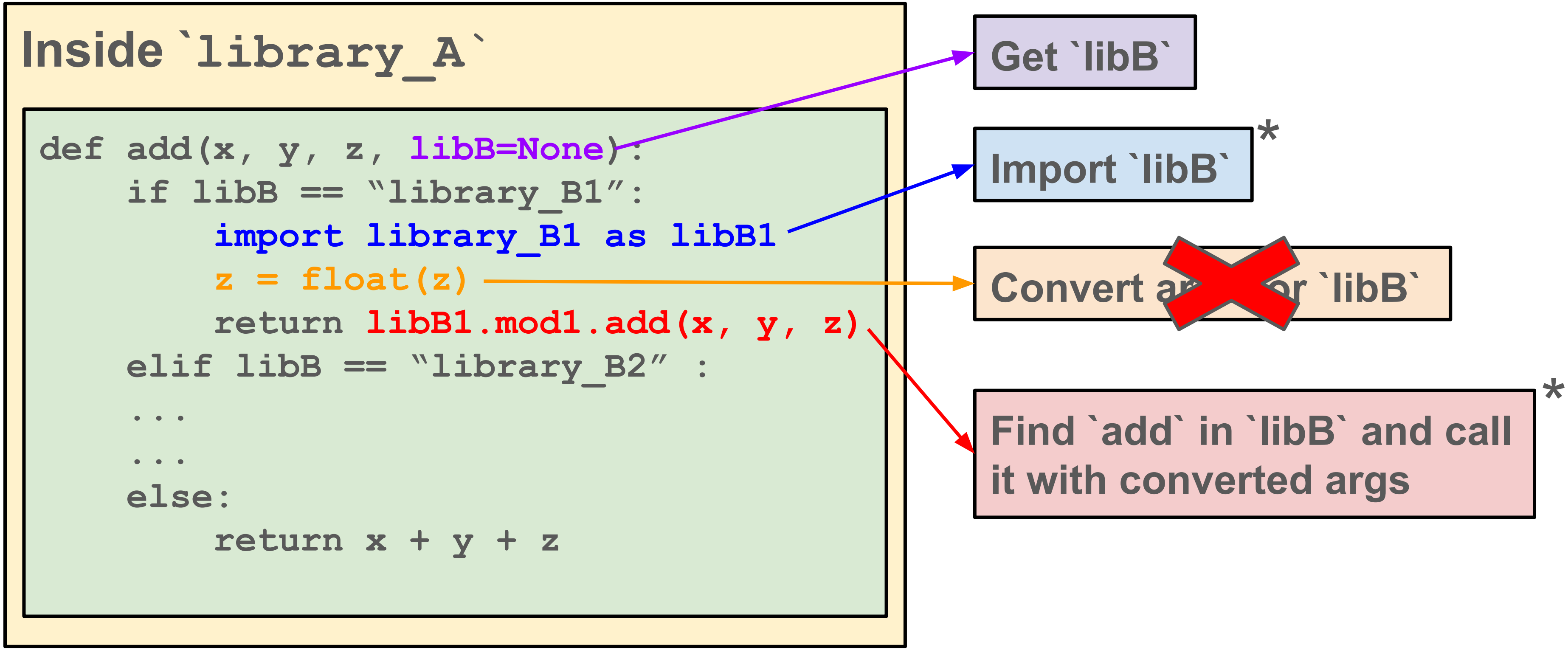
- can_run and should_run : quick checks by backend to optimise dispatching workflow
- Testing backend on NetworkX's test suite - `NETWORKX_TEST_BACKEND=”parallel”`
- Showing Backend docs in NetworkX docs (see here)
- Caching of converted graphs
- `.backends` attribute to get the set of all the installed backends that implement a particular function. For example:

  ```
  >>> nx.betweenness_centrality.backends
  {'parallel'}
  ```
- Specialised backend priority for algorithms, generators,.. etc.
- Logging
- Fallback

Read more at https://networkx.org/documentation/latest/reference/backends.html

Dispatching in NumPy for Arrays

Steps involved in dispatching



Inside `library_A`

```
def add(x, y, z, libB=None):
    if libB == “library_B1”:
        import library_B1 as libB1
        z = float(z)
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    elif libB == “library_B2” :
    ...
    ...
    else:
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```

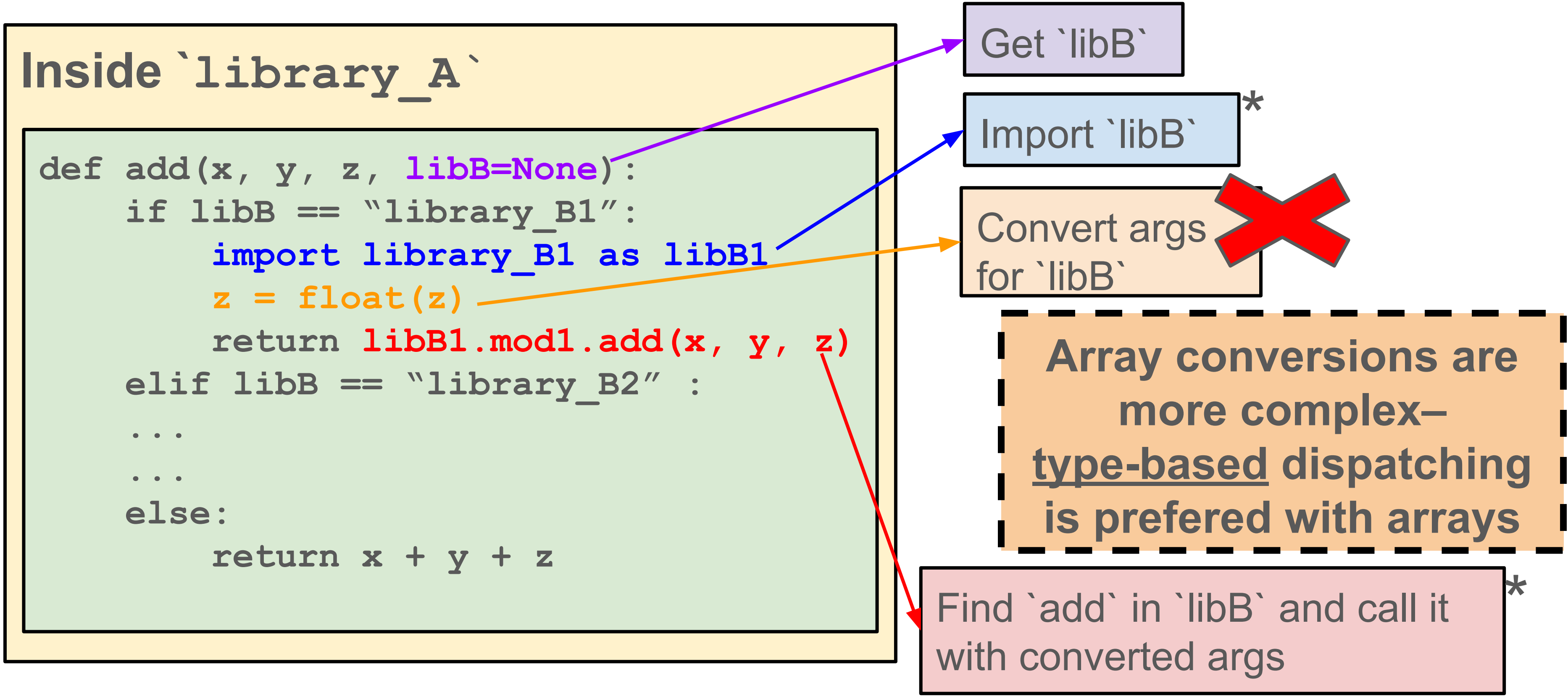
Get `libB`

Import `libB` *

~~Convert ar or `libB`~~

Find `add` in `libB` and call it with converted args *

Steps involved in dispatching



Inside `library_A`

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def add(x, y, z, libB=None):
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        z = float(z)
        return libB1.mod1.add(x, y, z)
    elif libB == “library_B2” :
    ...
    ...
    else:
        return x + y + z
```

Get `libB`

Import `libB`*

Convert args for `libB`

Array conversions are more complex– <u>type-based</u> dispatching is prefered with arrays

Find `add` in `libB` and call it with converted args*

Getting the backend implementation

```
input_array.__array_function__()
```

directly calls the apt. array library’s implementation, corresponding to the function that’s being called, if it exists.

Getting the backend implementation

`input_array.__array_function__()`

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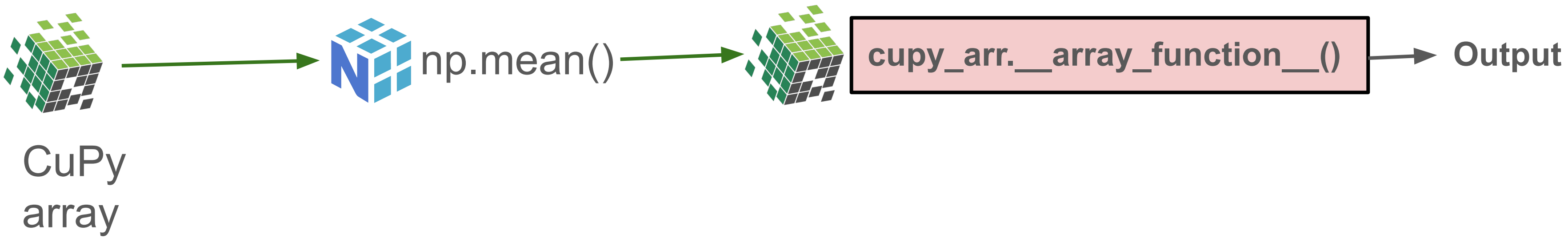

CuPy array

np.mean()

cupy_arr.__array_function__()

Output

Getting the backend implementation

```
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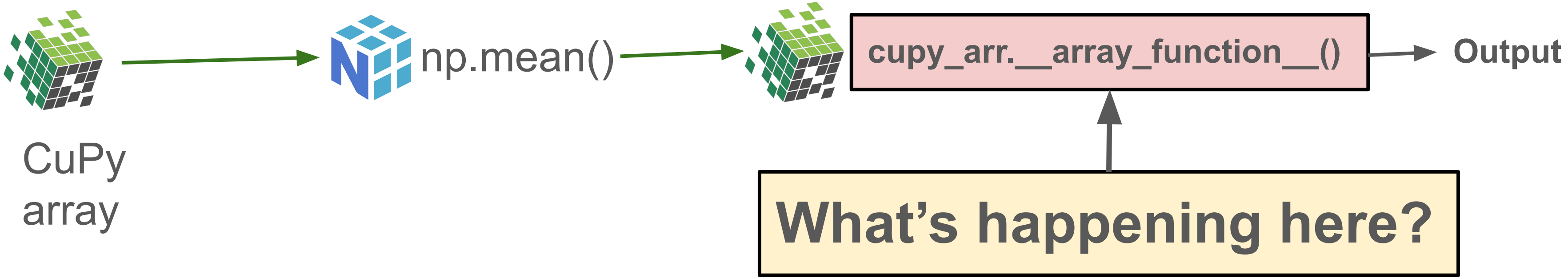


CuPy array

np.mean()

cupy_arr.__array_function__()

Output

What’s happening here?

Inside the CuPy (simplified)

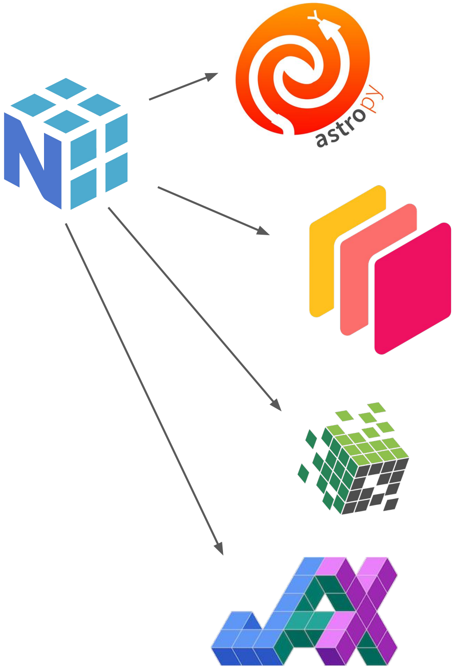
```
class ndarray:
  def __array_function__(self, func, types, *args, **kw):
      if not supported_function(func):  # np.mean not implemented
          return NotImplemented

      for t in types: # checking array types
          if not issubclass(t, (ndarray, numpy.ndarray)):
               return NotImplemented

      return cupy.mean(*args, **kw)
```

No fallbacks!

Dispatching in NumPy

- Started around ~2013:
  - `__array_ufunc__` (NEP 13)
    - subset (“universal functions”)
  - `__array_function__` (NEP 18 + 35)
    - almost all other functions.

- Use-cases/users:
  - SciPy sparse
  - `astropy.units` (“NumPy array of meters”)
  - Dask array (distributed)
  - CuPy (GPU), JAX, cupynumeric…



Dispatching in scikit-image

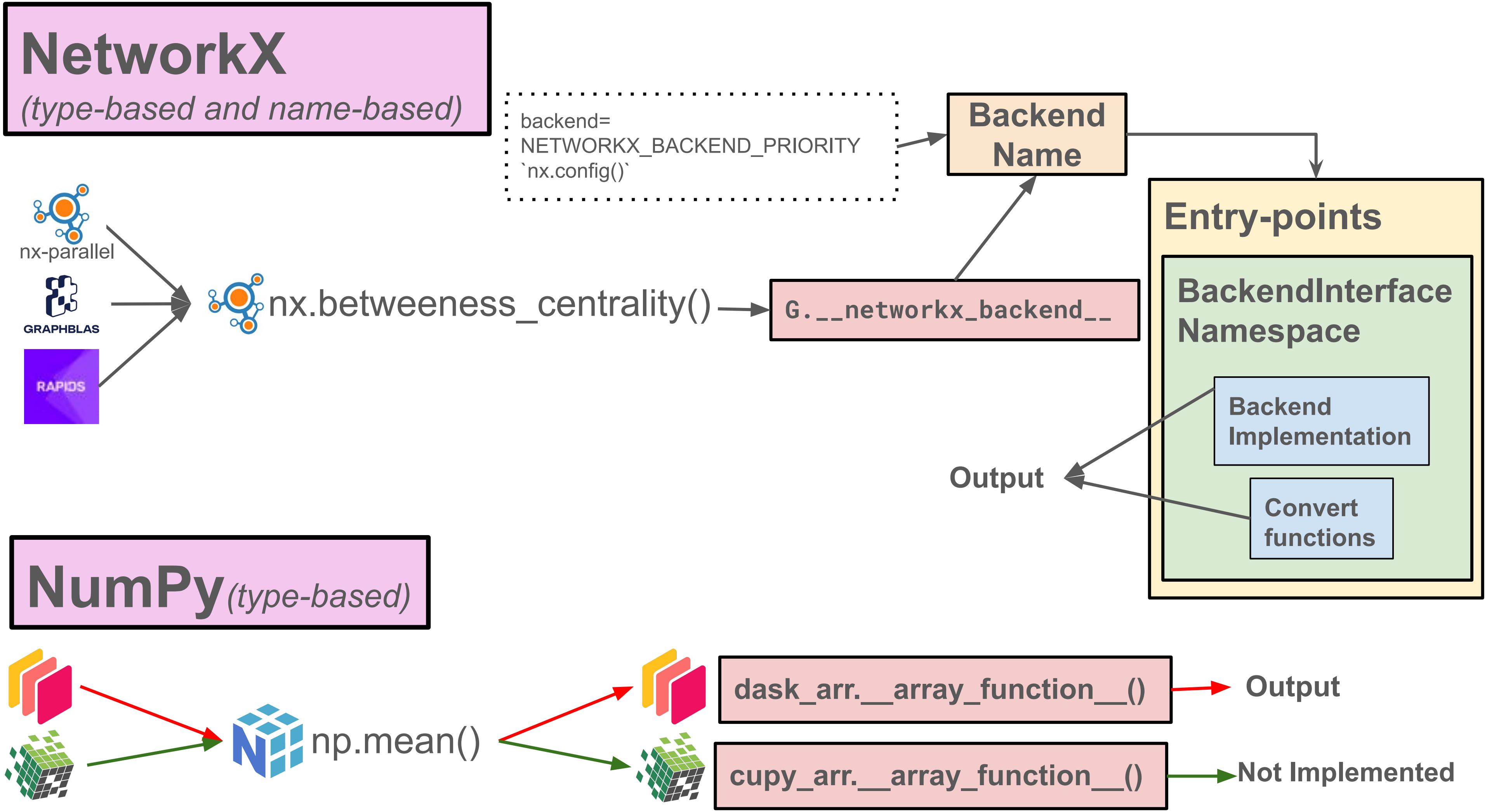
Dispatching in scikit-image

- **Challenge**: Hard to adopt Array API standards (Cython-heavy array consuming library)– therefore using entry-points for dispatching.

- **Goal**: want it to look like type-based dispatching internally entry-point based dispatching.

- **Current state**: No array conversions in dispatching code! – backend developers and users need to take care of the types. (Read more)

Possible Solution : https://github.com/scientific-python/spatch



NetworkX

(type-based and name-based)

nx-parallel

GRAPHBLAS

RAPIDS

nx.betweeness_centrality()

`G.__networkx_backend__`

backend=
NETWORKX_BACKEND_PRIORITY
`nx.config()`

Backend Name

Entry-points

BackendInterface Namespace

Backend Implementation

Convert functions

Output

NumPy *(type-based)*

np.mean()

dask_arr.__array_function__()

Output

cupy_arr.__array_function__()

Not Implemented

Next talk : Array API standards

Dispatching in Scientific Python ecosystem

- SPEC 2 : https://scientific-python.org/specs/spec-0002/
- spatch : https://github.com/scientific-python/spatch/
- Array API standards: https://data-apis.org/array-api/latest/
- NumPy’s type-based dispatching
  - https://numpy.org/neps/nep-0037-array-module.html
  - https://numpy.org/neps/nep-0047-array-api-standard.html
- NetworkX
  - https://networkx.org/documentation/latest/reference/backends.html
  - https://networkx.org/documentation/latest/reference/configs.html
  - Dispatch meetings:https://scientific-python.org/calendars/networkx.ics
  - https://github.com/networkx/networkx/issues?q=is%3Aissue%20state%3Aopen%20label%3ADispatching
- Scikit-image
  - scikit-image-PR#7520
  - https://github.com/scikit-image/scikit-image/pull/7727
  - https://github.com/rapidsai/cucim/issues/829
- Scikit-learn
  - https://github.com/scikit-learn/scikit-learn/pull/30250
  - https://youtu.be/f42C1daBNrg?si=A9mZ2mZd2HzEhu8S
- SciPy’s Array API adoption
  - https://docs.scipy.org/doc/scipy/dev/api-dev/array_api.html
  - https://youtu.be/16rB-fosAWw?si=ys_-ZTnUKvO_aZKu
- DataFrame API standards
  - https://github.com/narwhals-dev/narwhals
  - https://data-apis.org/dataframe-api/draft/
- Scientific Python discord(#dispatching thread): https://discord.com/invite/vur45CbwMz

FIN.