

Tutorial on Computational Design for Robotics



Co-design hands-on tutorial

Overview

- ▶ Environment setup
- ▶ Language tutorial
- ▶ Continuing the example from the first part





Environment setup



Two ways to run the code

- ▶ **Option 1: Using the website [editor.zuper.ai](#)**

- requires a Github account to link to the Github app
- a convenient visual editor
- much better error reporting
- fewer options than the command line interface

- ▶ **Option 2: Using Docker on the command line**

- requires Docker on your computer
- command line interaction
- better for longer queries



Using the Docker version

- ▶ Requires basic knowledge of Docker.

- ▶ Pull the following image:

```
docker pull zupermind/mcdp:2023
```

- ▶ Inside the image there are various command-line programs:

- mcdp-solve - solves a query
 - mcdp-plot - plots a design problem

- ▶ **One shot run** of the mcdp-solve program:

- docker run -it --rm -v \$PWD:\$PWD -w \$PWD zupermind/mcdp:2023 mcdp-solve --help

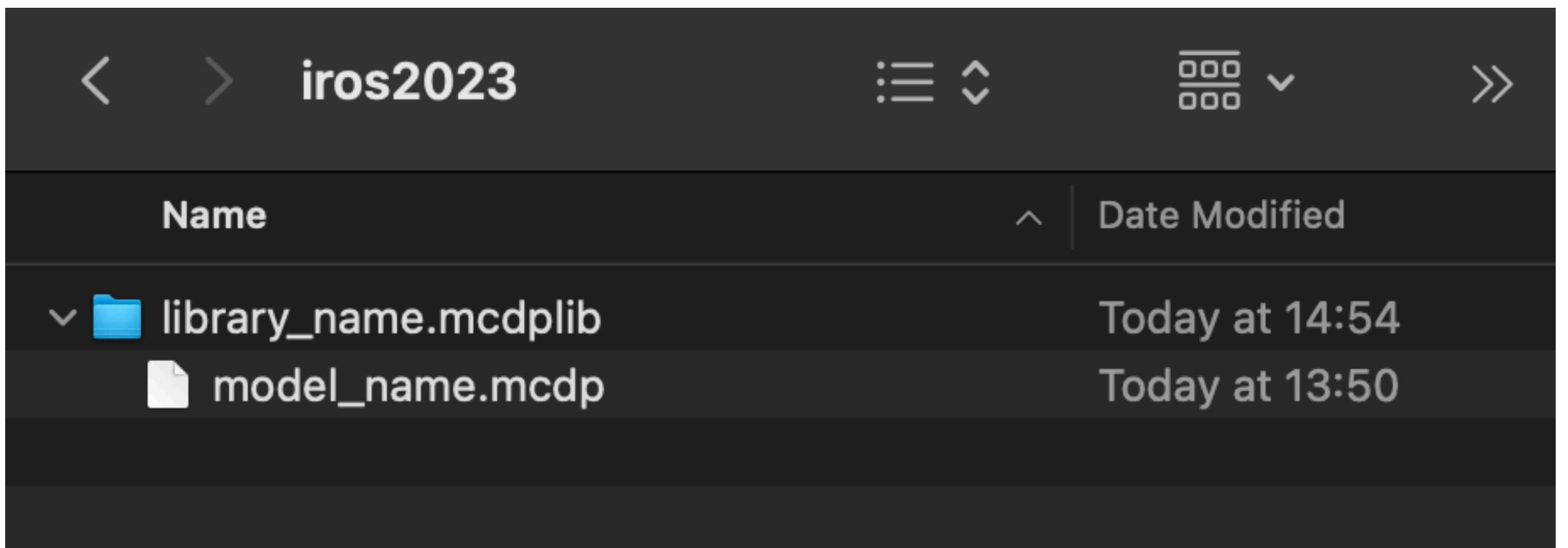
- ▶ **Run a session** like this:

- docker run -it --rm -v \$PWD:\$PWD -w \$PWD zupermind/mcdp:2023 bash



Directory structure

- We organize the code in *libraries*.
- **Libraries are directories** named **LIBNAME.mcdplib**
 - Libraries cannot be nested.
- **Inside the library directory** we can have various types of files.
 - **Models:** **model_name.mcdp**
 - Poset definitions: **poset_name.mcdp_poset**
 - Templates: **template_name.mcdp_template**
 - ...

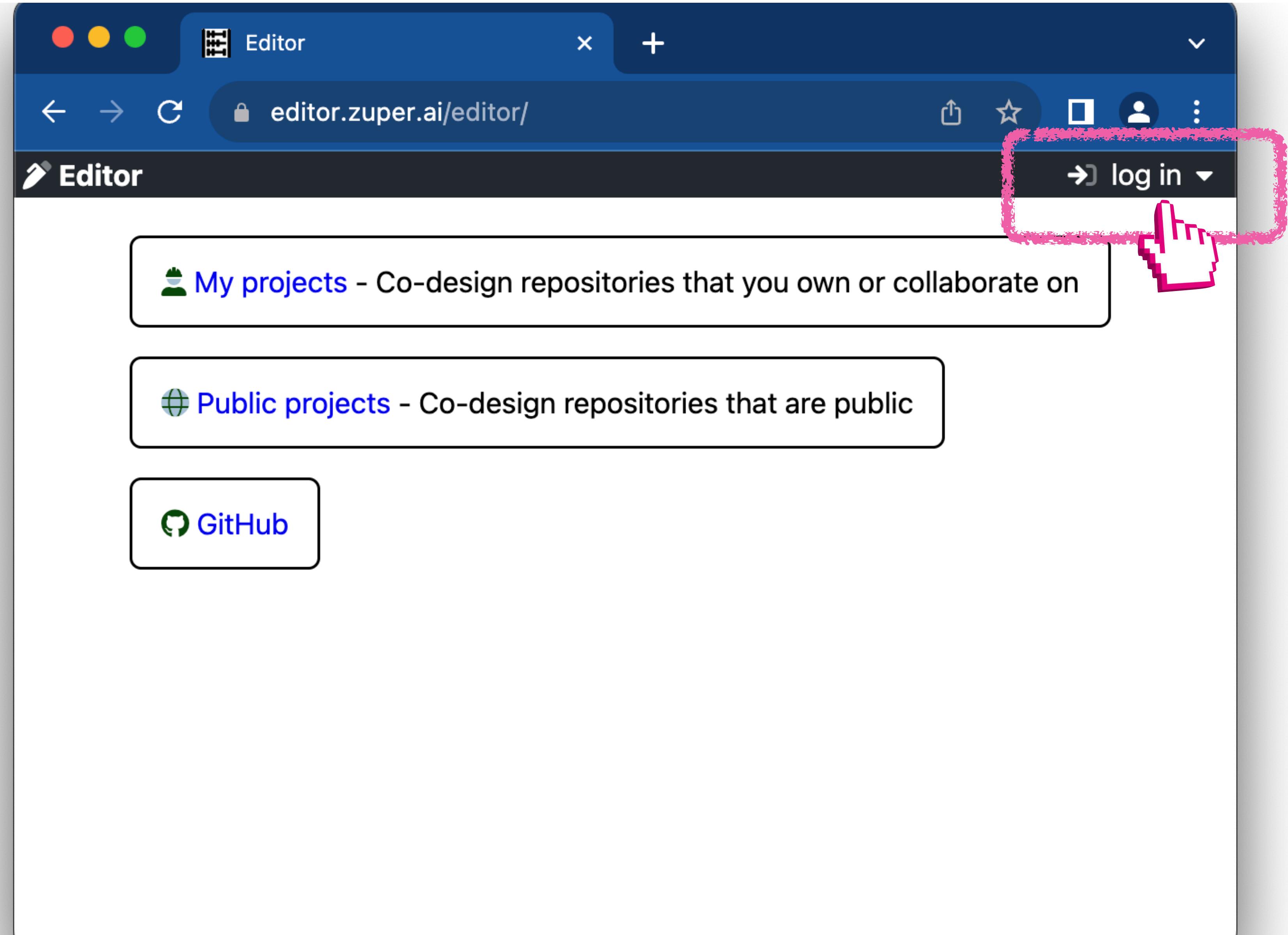


Web editor

- There is a **Github app** reachable at **editor.zuper.ai**
- You have to **install the app into one of the Github organizations** that you control.
- The data is stored on a Github repository of which you are admin.
 - You can edit this repository also by external means, and it will sync up.



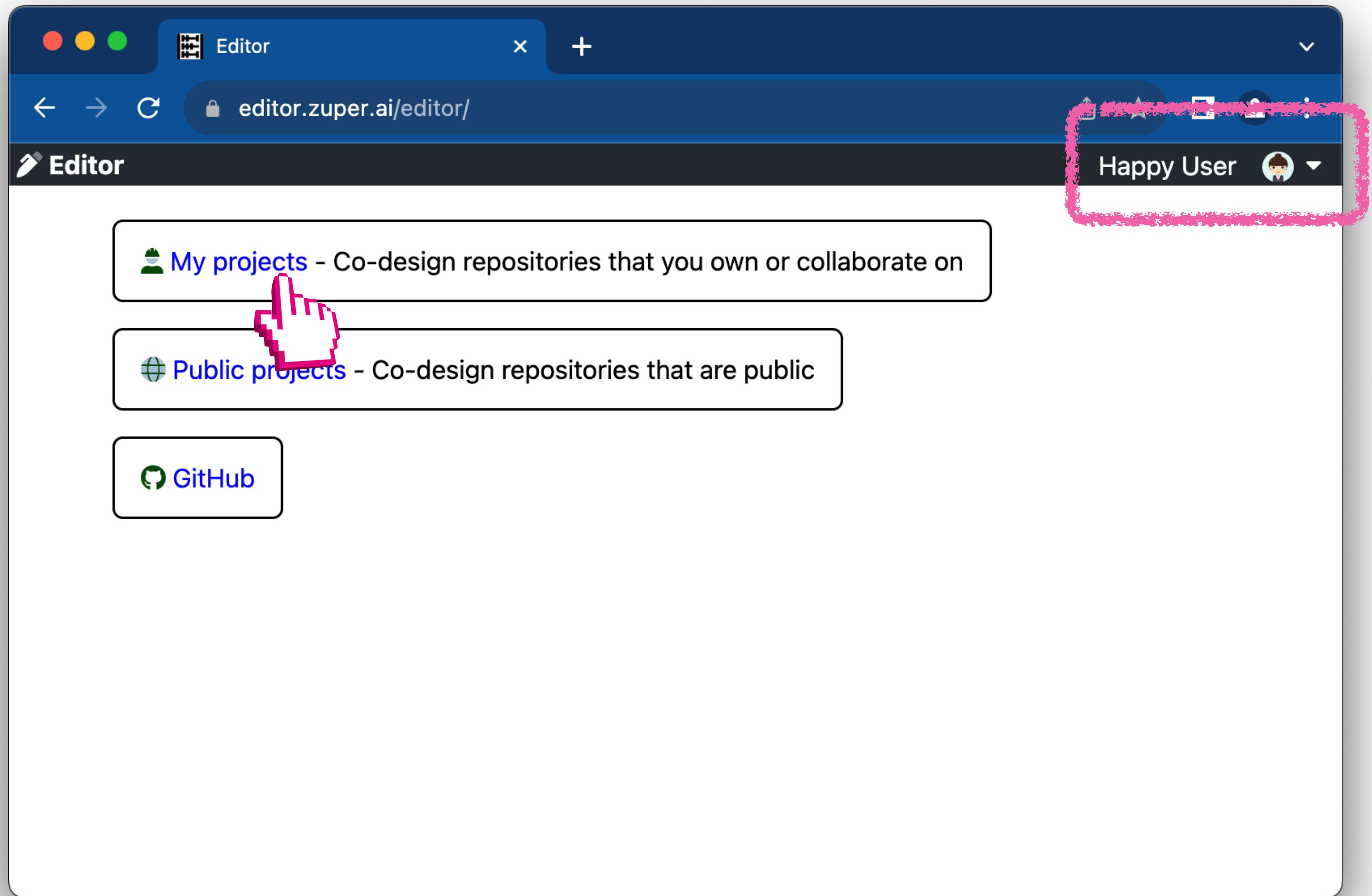
Go to editor.zuper.ai



log in with Github account



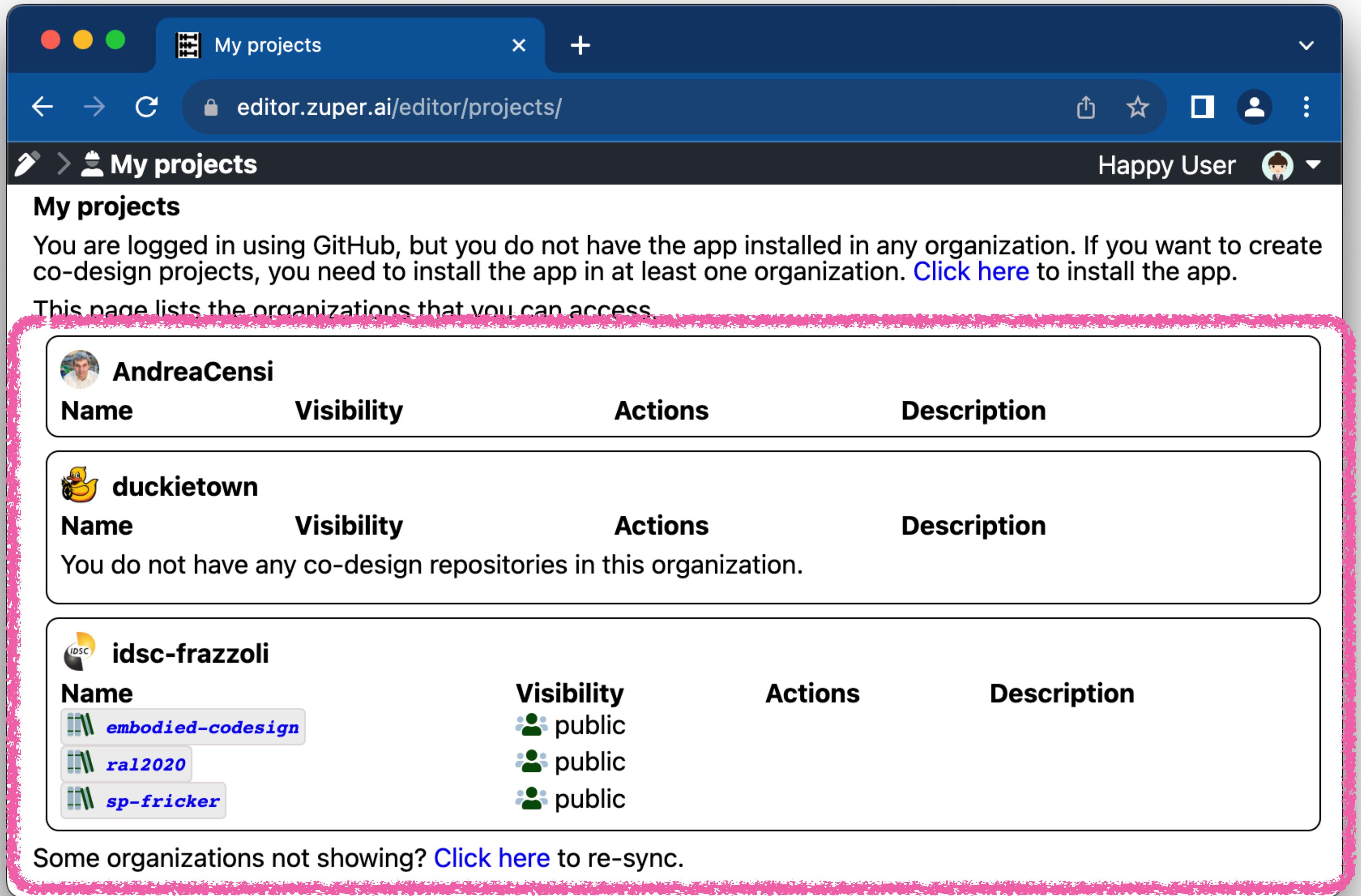
- Logged in = you can access the repositories of your organizations that already have the app installed. Permissions = Github permissions.



logged in



- Logged in = you can access the repositories of your organizations that already have the app installed. Permissions = Github permissions.

A screenshot of a web browser window titled "My projects". The URL is "editor.zuper.ai/editor/projects/". The page displays a list of organizations the user belongs to, each with a thumbnail, name, visibility, actions, and description. A pink border highlights the main content area.

Name	Visibility	Actions	Description
 AndreaCensi			
 duckietown			
 idsc-frazzoli			

You are logged in using GitHub, but you do not have the app installed in any organization. If you want to create co-design projects, you need to install the app in at least one organization. [Click here](#) to install the app.

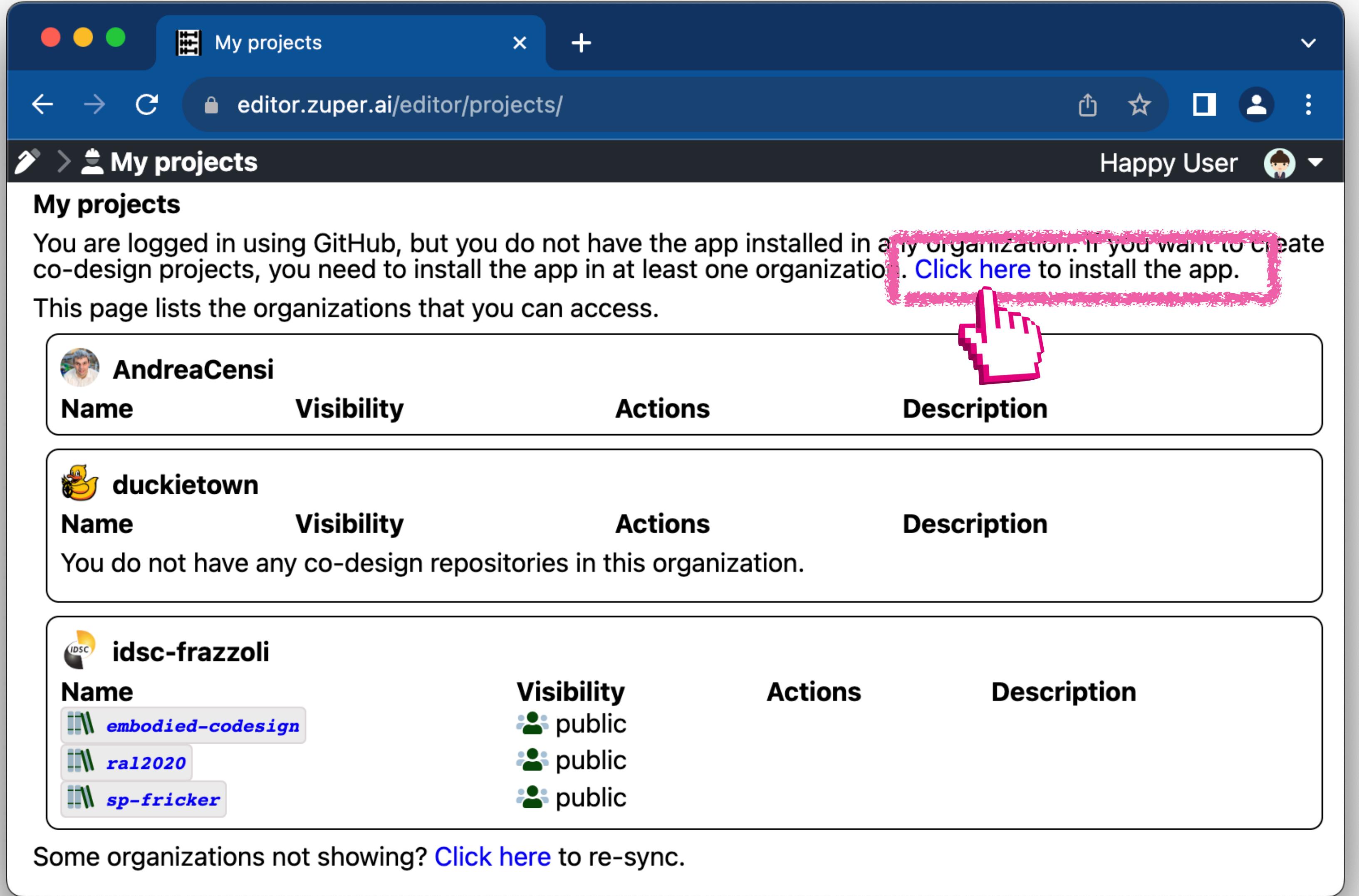
This page lists the organizations that you can access.

Some organizations not showing? [Click here](#) to re-sync.

organizations to which you already belong that have installed the app



- ▶ **Install the app** to give it access to one of the organizations you control.



My projects

editor.zuper.ai/editor/projects/

Happy User

My projects

You are logged in using GitHub, but you do not have the app installed in any organization. If you want to create co-design projects, you need to install the app in at least one organization. [Click here](#) to install the app.

This page lists the organizations that you can access.

Name	Visibility	Actions	Description
 AndreaCensi			
 duckietown			
 idsc-frazzoli			

AndreaCensi

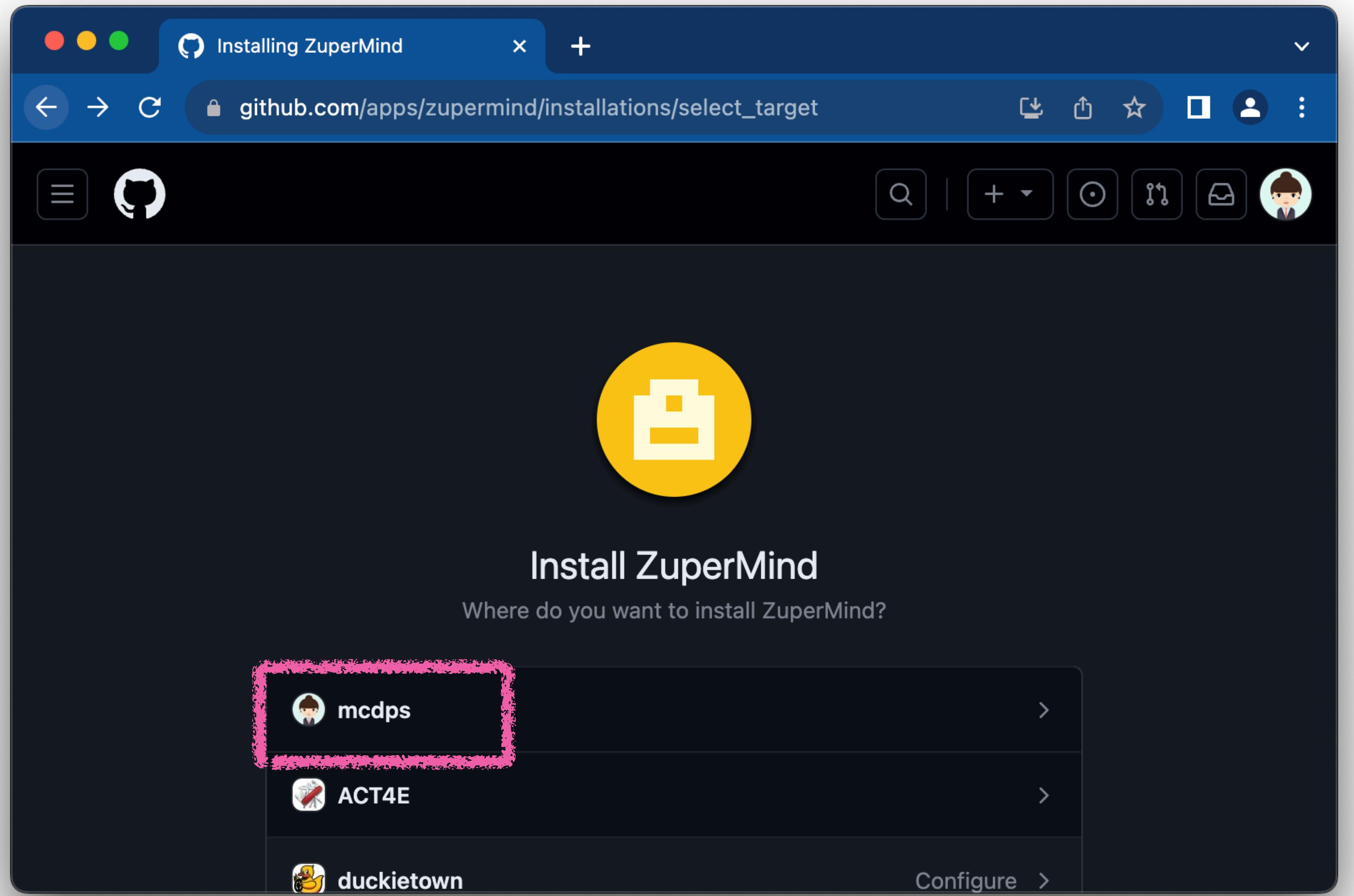
duckietown

idsc-frazzoli

Some organizations not showing? [Click here](#) to re-sync.

*install the app to other organizations
(including your personal one)*





your organization



My projects x +

editor.zuper.ai/editor/projects/ ↑ ☆ □ 👤 ⋮

Name	Visibility	Actions	Description
 duckietown			
Name	Visibility	Actions	Description
You do not have any co-design repositories in this organization.			

Name	Visibility	Actions	Description
 idsc-frazzoli			
Name	Visibility	Actions	Description
 embodied-codesign	 public		
 ral2020	 public		
 sp-fricker	 public		

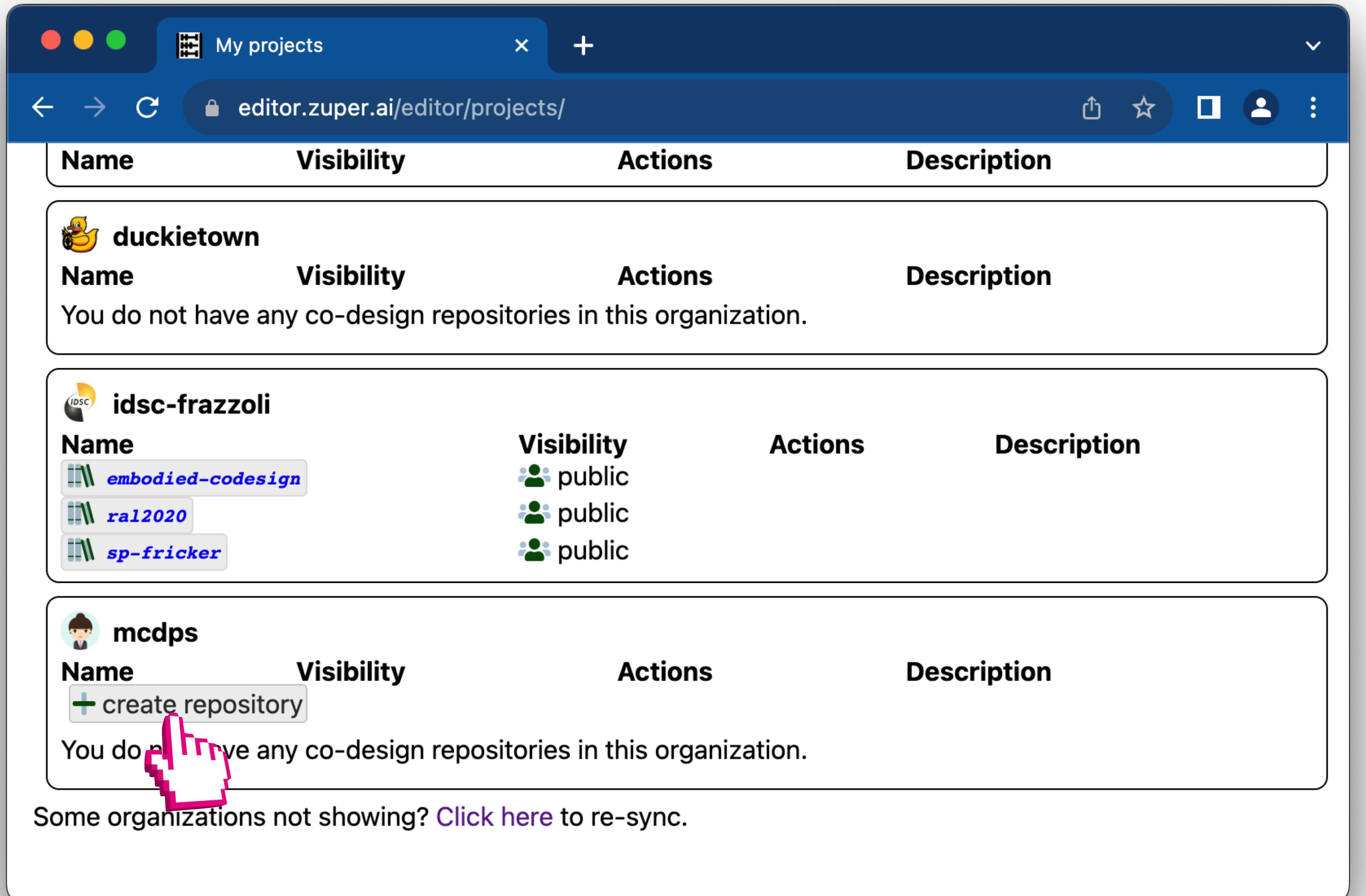
Name	Visibility	Actions	Description
 mcdps			
Name	Visibility	Actions	Description
 + create repository			
You do not have any co-design repositories in this organization.			

Some organizations not showing? [Click here](#) to re-sync.

Organization added



Creating a repository



The screenshot shows a web browser window with a dark blue header bar. The title bar says "My projects" with a "x" and a "+" button. Below the header is a navigation bar with back, forward, and search buttons, and a URL bar showing "editor.zuper.ai/editor/projects/". To the right of the URL bar are icons for upload, star, refresh, user profile, and more.

The main content area displays three sections of repositories:

- duckietown**: Shows one repository named "embodied-codesign" with "public" visibility.
- idsc-frazzoli**: Shows three repositories: "embodied-codesign", "ral2020", and "sp-fricker", all with "public" visibility.
- mcdps**: Shows a "create repository" button and a message "You do not have any co-design repositories in this organization." A hand cursor icon is hovering over the "create repository" button.

At the bottom left, there is a link: "Some organizations not showing? [Click here](#) to re-sync." A small red and white tool icon is in the bottom right corner.

Create a co-design repository



Creating a repository

The screenshot shows a web browser window titled "My projects" at the URL "editor.zuper.ai/editor/projects/". A modal dialog box is open, prompting the user to "Create a new repository in m...". The input field contains the text "iros2023". A hand cursor is hovering over the "OK" button, which is highlighted with a pink glow. The background shows a list of organizations: "duckietown", "idsc-frazzoli", and "mcdps". The "idsc-frazzoli" organization has three repositories listed: "embodied-codesign", "ral2020", and "sp-fricker". The "mcdps" organization has a "create repository" button. A message at the bottom states, "You do not have any co-design repositories in this organization." A footer note says, "Some organizations not showing? Click here to re-sync.".

My projects

editor.zuper.ai/editor/projects/

Name	Visibility	Actions	Description
duckietown			
Name	Visibility	Actions	Description
You do not have any co-design repositories in this organization.			

Name	Visibility	Actions	Description
idsc-frazzoli			Description
embodied-codesign			
ral2020			
sp-fricker			
mcdps			Description
Name	Visibility	Actions	Description
+ create repository			
You do not have any co-design repositories in this organization.			

Create a new repository in m...

Please enter a name for the new repository. **iros2023**

OK Cancel

Some organizations not showing? [Click here](#) to re-sync.

My projects x +

editor.zuper.ai/editor/projects/ ↑ ☆ □ 👤 ⋮

duckietown

Name	Visibility	Actions	Description
You do not have any co-design repositories in this organization.			

idsc-frazzoli

Name	Visibility	Actions	Description
<code>embodied-codesign</code>	public		
<code>ral2020</code>	public		
<code>sp-fricker</code>	public		

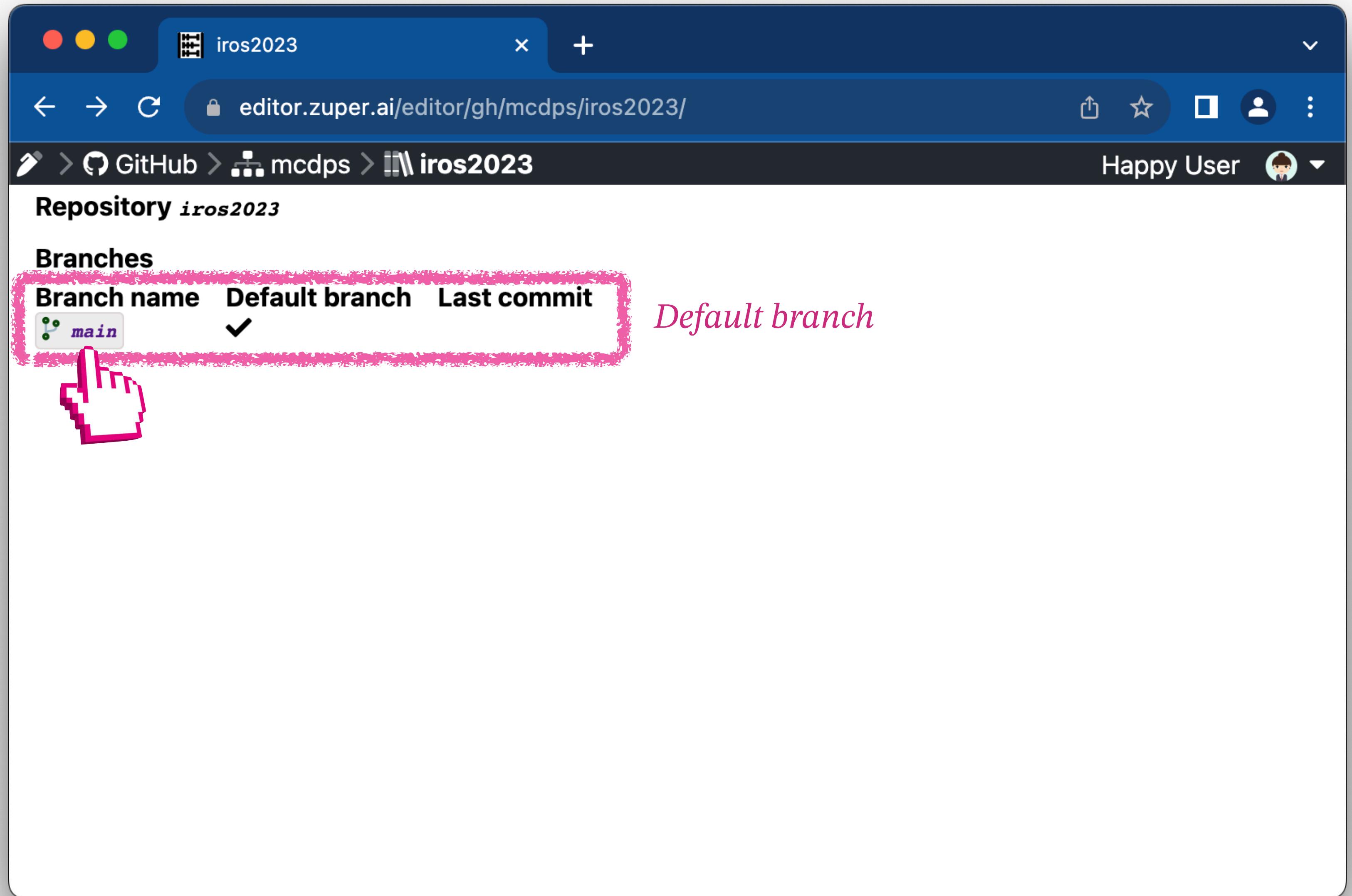
mcdps

Name	Visibility	Actions	Description
<code>iros2023</code>	private	rename delete make public	
Create repository			
You do not have any co-design repositories in this organization.			

Some organizations not showing? [Click here](#) to re-sync.



Edit a repository



A screenshot of a web browser window showing a GitHub repository page. The title bar says "iros2023". The address bar shows the URL "editor.zuper.ai/editor/gh/mcdps/iros2023/". The page header includes "GitHub > mcdps > iros2023" and "Happy User". The main content is titled "Repository *iros2023*". Under "Branches", there is a table:

Branch name	Default branch	Last commit
main	✓	

A pink box highlights the first row of the table, and a pink hand cursor points to the "main" button. The text "Default branch" is written in pink next to the table.



Edit a repository

Branch **main**

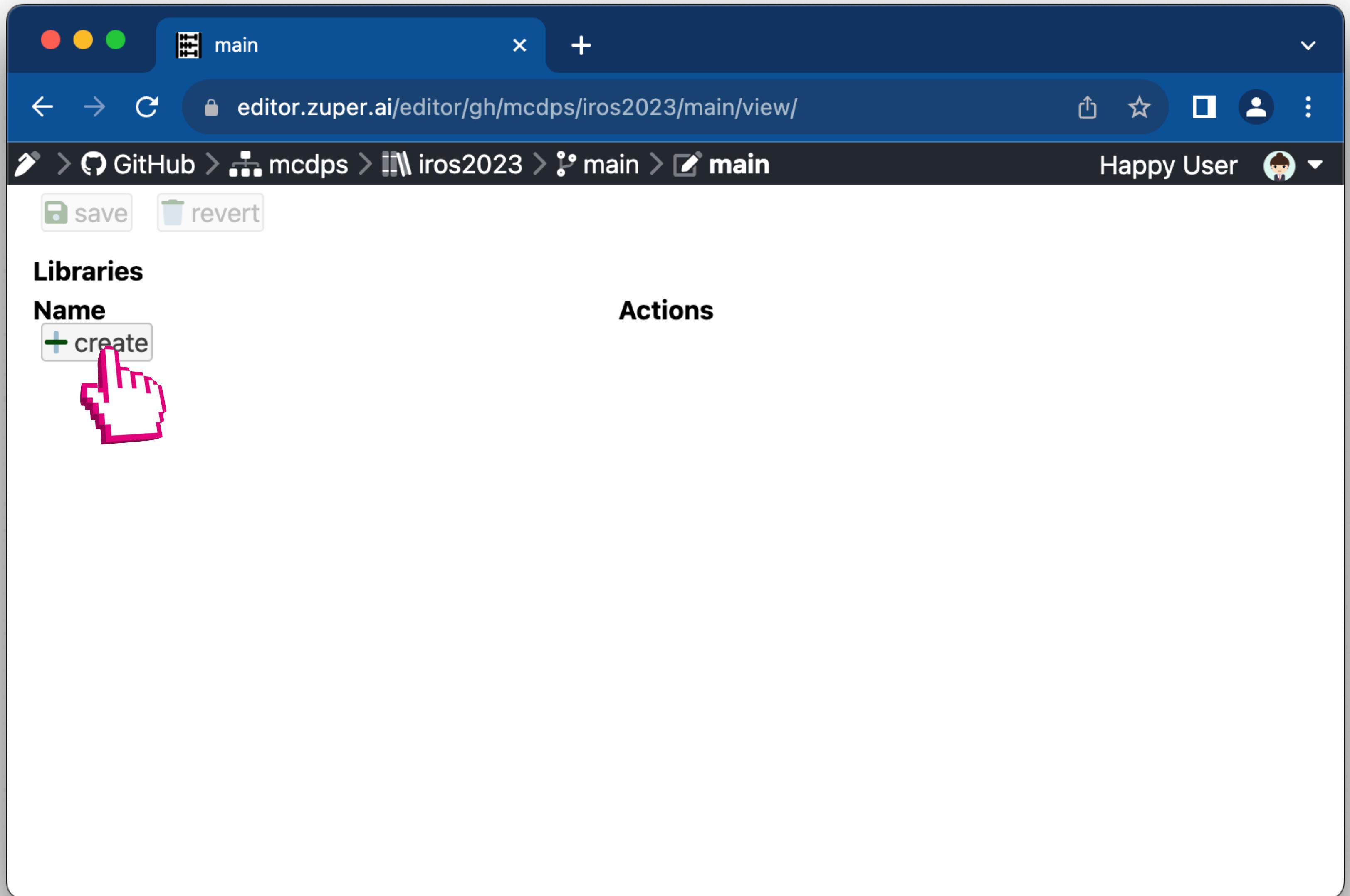
[View this branch.](#)

History [commits](#)

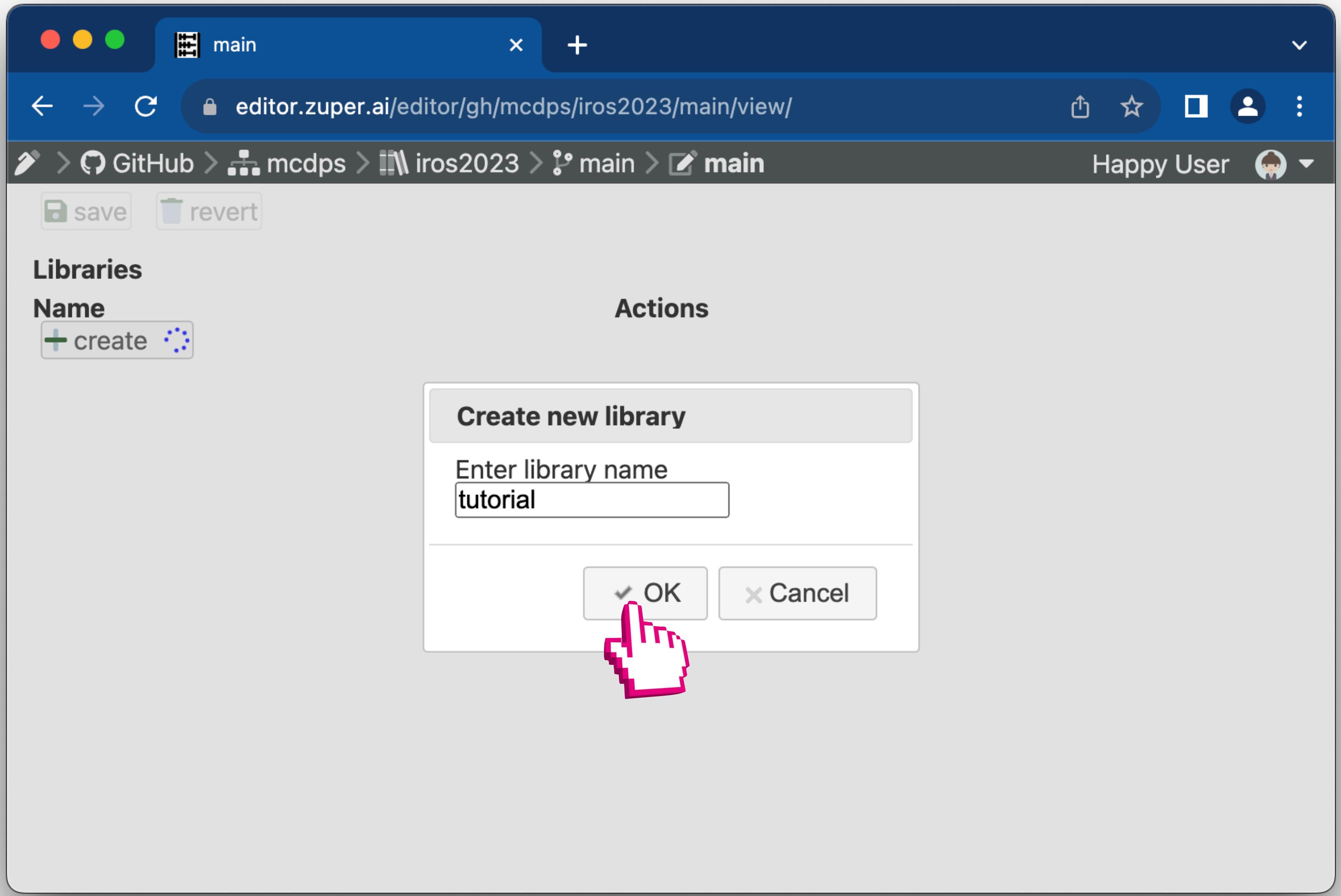
Date	SHA	author
41 s	3df416f	ZuperBot
1 h, 59 m	49ab414	Happy User



The libraries interface



The libraries interface



Creating a model

The screenshot shows a web browser window titled "tutorial" with the URL editor.zuper.ai/editor/gh/mcdps/iros2023/main/view/libraries/tutorial/. The page displays a file structure: GitHub > mcdps > iros2023 > main > main > tutorial. A user "Happy User" is logged in.

models

Name	Actions	Views

+ create

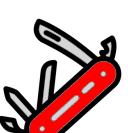
temp (highlighted with a pink cursor)

Actions **Views**

posets

Name	Actions	Views

+ create



Creating a model

The screenshot shows a web browser window titled "tutorial" with the URL editor.zuper.ai/editor/gh/mcdps/iros2023/main/view/libraries/tutorial/. The page displays a "models" section with a table header "Name Actions Views". Below this, there is a "create" button with a plus sign and a circular icon. A modal dialog box is open, titled "Create new object", containing a text input field with the value "myrobot". A pink hand cursor is pointing at the "OK" button, which has a checkmark icon. The "templates" and "posets" sections are also visible on the left.

models

Name	Actions	Views
------	---------	-------

+ create

templates

Name	A
------	---

+ create

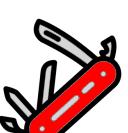
posets

Name	Actions	Views
------	---------	-------

Create new object

Enter object name
myrobot

✓ OK ✖ Cancel



Creating a model

tutorial

editor.zuper.ai/editor/gh/mcdps/iros2023/main/view/libraries/tutorial/

GitHub > mcdps > iros2023 > main > main > tutorial

Added object myrobot

save revert

models

Name	Actions	Views
myrobot	Delete Rename	

+ create

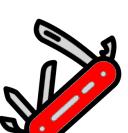
templates

Name	Actions	Views

+ create

posets

Name	Actions	Views



Seeing the model code

- ▶ You will see a read-only interface to the code.

A screenshot of a web browser window titled "myrobot". The address bar shows the URL "editor.zuper.ai/editor/gh/mcdps/iros2023/main/view/libraries/tutorial/s...". The page content is a code editor with the following code:

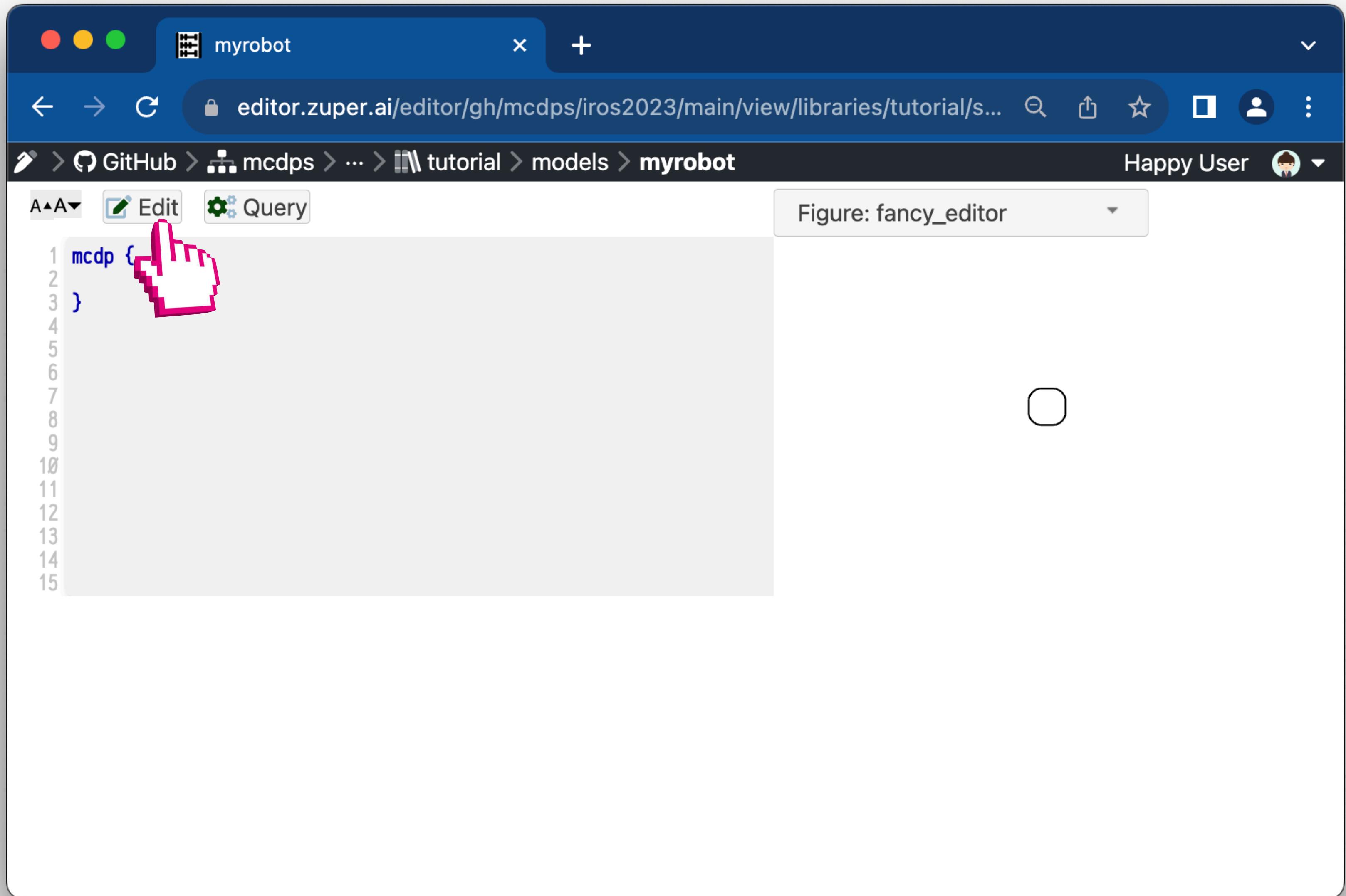
```
1 mcdp {  
2 }  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15
```

The code editor has a toolbar with "Edit" and "Query" buttons. A dropdown menu above the code area says "Figure: fancy_editor". The right side of the editor is currently empty, showing a small circular icon.



Editing the code

- If you have **edit access** to this repository (according to Github permissions) you can open the **editing interface**.



Editing the code

- New options: **Save** and **Revert**
- **Save** = commit to the repository

The screenshot shows a web browser window with a dark blue header bar. The title bar reads "myrobot edit". The address bar shows the URL "editor.zuper.ai/editor/gh/mcdps/iros2023/main/view/libraries/tutorial/s...". The navigation bar includes icons for back, forward, search, and user profile. Below the header is a breadcrumb navigation path: "GitHub > mcdps > ... > tutorial > models > myrobot > myrobot edit". On the right side of the header, it says "Happy User" with a profile icon. The main content area contains a code editor with the following text:
1 mcdp {
2
3 }
4
5
6
7
8
9
10
11
12
13
14
15



Committing

myrobot edit

editor.zuper.ai/editor/gh/mcdps/iros2023/main/view/libraries/tutorial/s...

GitHub > mcdps > ... > tutorial > models > myrobot > myrobot edit Happy User

save revert A▲A▼ Beautify Query

Figure: fancy_editor

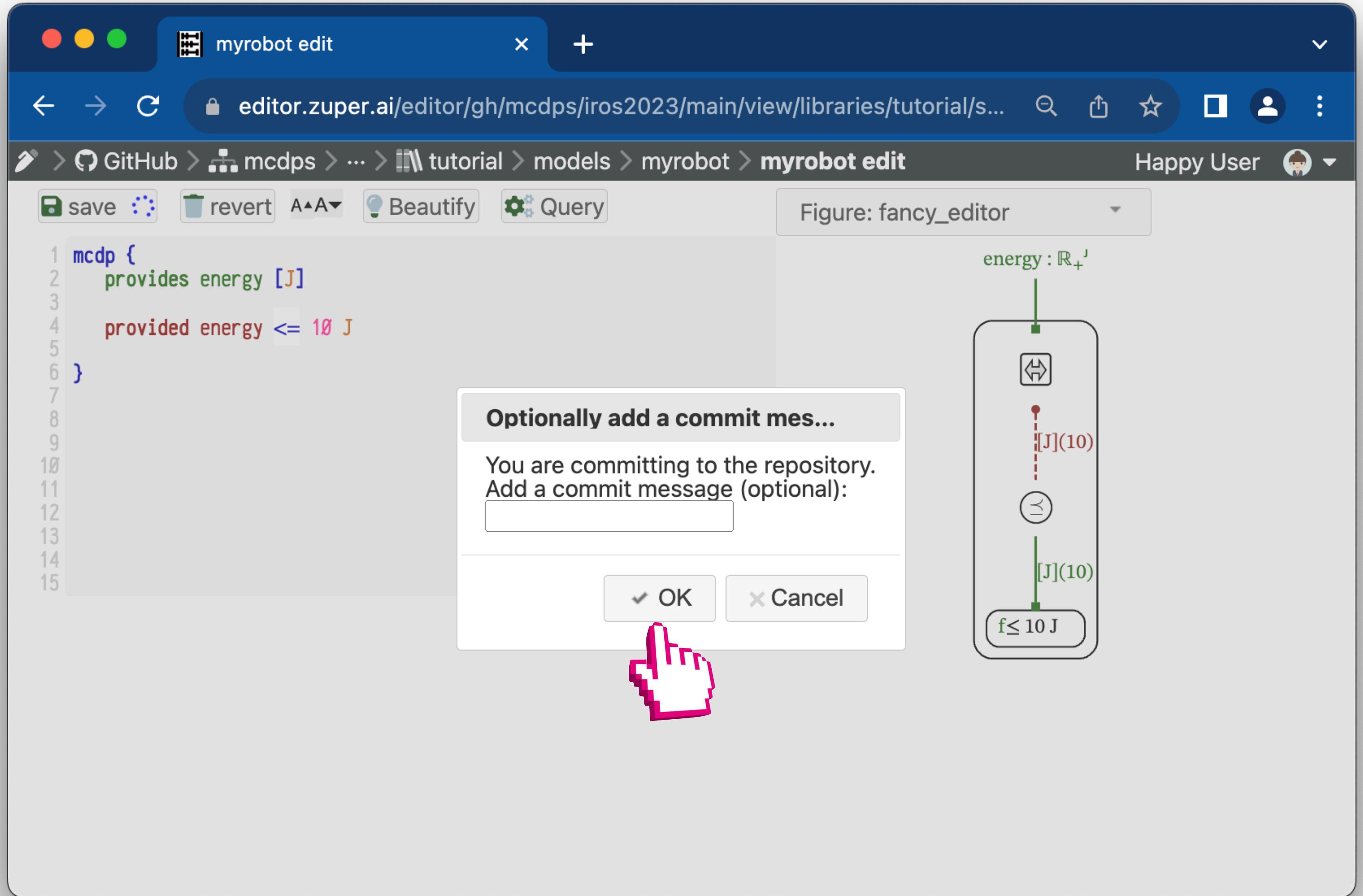
```
2 provides energy [J]
3
4 provided energy <= 10 J
5 }
```

energy : \mathbb{R}_+

The diagram illustrates a robot model with the following components and connections:

- A central rectangular body contains:
 - A double-headed arrow symbol.
 - A red dot labeled $[J](10)$.
 - A circular arrow symbol.
 - A green line labeled $[J](10)$ pointing downwards to a box.
- A green line labeled $f \leq 10 J$ points from the bottom of the central body to a box at the bottom.
- A green line labeled $energy : \mathbb{R}_+$ points upwards from the top of the central body to a box at the top.

Committing



Meanwhile, on Github...

- All data is stored on your Github repository.
- You can edit this by other means and it will sync up.

A screenshot of a Mac OS X desktop environment showing a web browser window. The window title is "query" and the tab title is "iros2023/tutorial.mcdplib at main · iros2023/tutorial.mcdplib". The URL in the address bar is "github.com/mcdps/iros2023/tree/main/tutorial.mcdplib". The browser interface includes standard controls like back, forward, and search, along with GitHub-specific icons for code, issues, pull requests, actions, projects, security, and insights.

The main content area displays a GitHub repository page for "iros2023 / tutorial.mcdplib". The repository has one branch, "main", which is the active branch. A message from "mcdps" states "No message given." and was committed 15 hours ago. The commit history shows a single entry with the same message and timestamp.

Name	Last commit message	Last commit date
..	No message given.	15 hours ago
myrobot.mcdp	No message given.	15 hours ago



Query interface

myrobot edit

editor.zuper.ai/editor/gh/mcdps/iros2023/main/view/libraries/tutorial/s...

GitHub > mcdps > ... > tutorial > models > myrobot > myrobot edit Happy User

save revert A▲A▼ Beautify Query Figure: fancy_editor

```
1 mcdp {  
2   provides energy [J]  
3  
4   provided energy <= 10 J  
5 }
```

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

The diagram illustrates a robot model with the following components and constraints:

- A central rectangular body with a double-headed arrow symbol.
- An energy source at the top labeled $\text{energy} : \mathbb{R}_+$.
- A red dashed vertical line labeled $[J](10)$ extending downwards from the center.
- A green dashed vertical line labeled $[J](10)$ extending downwards from the center.
- A green box at the bottom labeled $f \leq 10 \text{ J}$.
- A small circular arrow symbol near the bottom center.

Query interface

The screenshot shows a web browser window titled "query" with the URL "editor.zuper.ai/editor/gh/mcdps/iros2023/main/view/libraries/tutorial/s...". The browser's address bar also displays "GitHub > mcdps > ... > tutorial > models > myrobot > query". The user is logged in as "Happy User".

1. Choose a query type

Fixed the functionality, minimize resources.

Given the resources, maximize the functionality.

- Given an implementation, evaluate functionality/resources. [no UI]
- Given min functionality and max resources, determine if there is a feasible implementation. [no UI]
- Given min functionality and max resources, find an implementation. [no UI]
- Solve for X: find the minimal component that makes the design problem feasible. [no UI]



Query interface

query

← → C 🔒 editor.zuper.ai/editor/gh/mcdps/iros2023/main/view/libraries/tutorial/s...

1. Choose a query type

Fixed the functionality, minimize resources.

Fixed the resources, maximize the functionality.

Given an implementation, evaluate functionality/resources. [no UI]

Given min functionality and max resources, determine if there is a feasible implementation. [no UI]

Given min functionality and max resources, find an implementation. [no UI]

Solve for X: find the minimal component that makes the design problem feasible. [no UI]

2. Choose the query parameters

100 J
= 100 J

energy
 \mathbb{R}_+^J

minimize 1
such that energy \geq 100 J

\mathcal{F} f h \mathcal{R} $h(f)$

functionality resources

