PPO×Family

第三讲：表征多模态观察空间

主办 中国计算机学会 CCF

承办 上海人工智能实验室 Shanghai Artificial Intelligence Laboratory

协办 GAIAA 北京大学人工智能研究院 INSTITUTE FOR ARTIFICIAL INTELLIGENCE, PEKING UNIVERSITY 浙江大学上海高等研究院 SHANGHAI INSTITUTE FOR ADVANCED STUDY ZHEJIANG UNIVERSITY 商汤 sensetime

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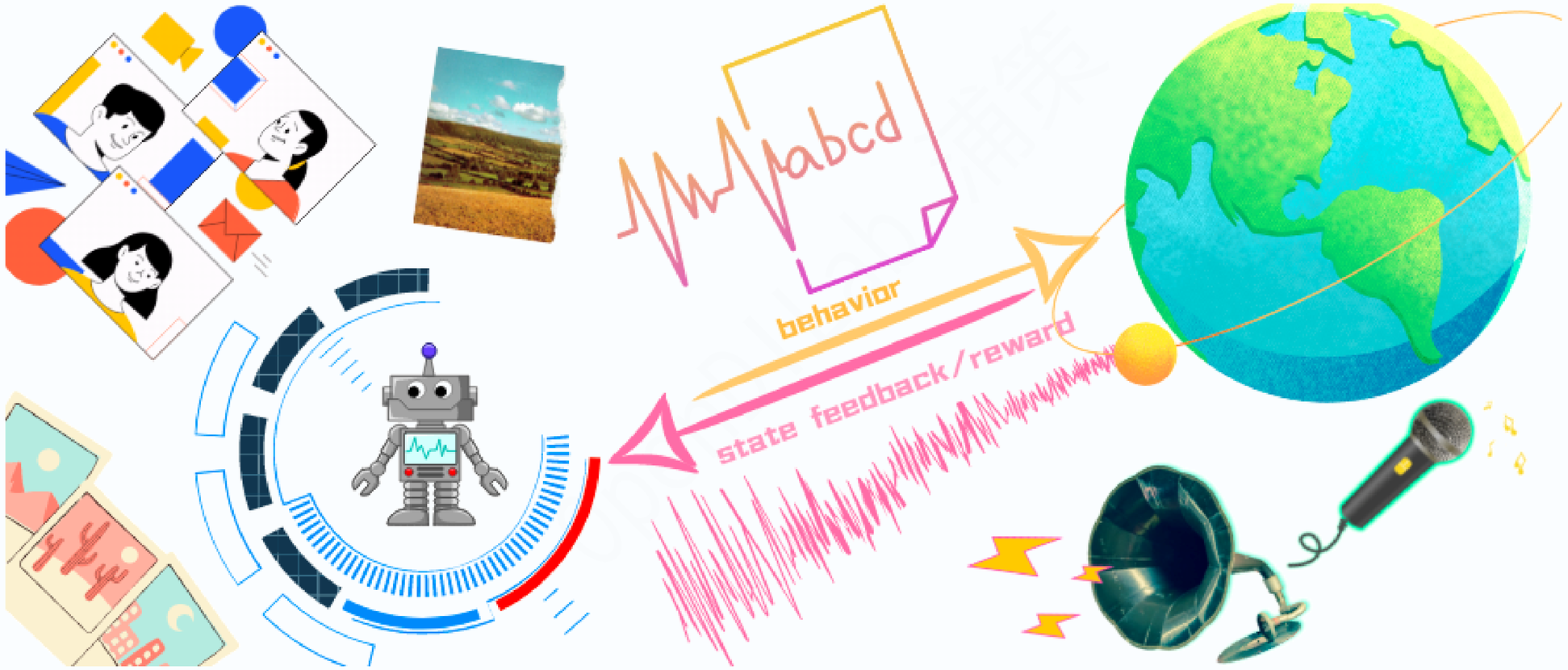
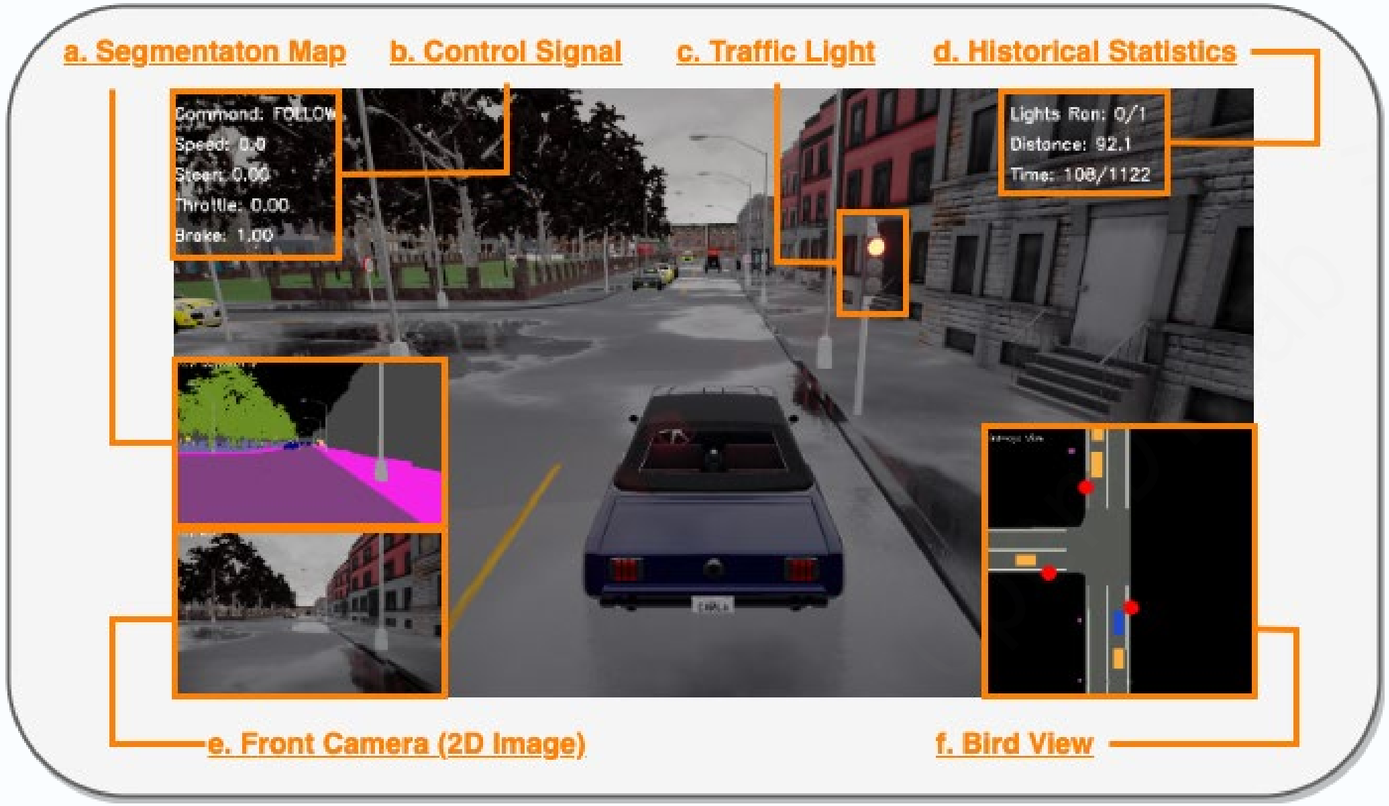
观察空间三部曲

Obs Space Overview

观察空间概述



常见的观察空间类型



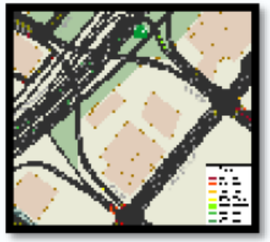
特点：

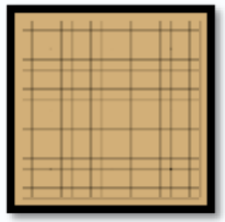
- 特征预处理可以事半功倍
- 高维的观察信息更需要专门设计的神经网络架构
- 复杂的决策问题往往包含多种模态的观察信息

Encoder

编码器

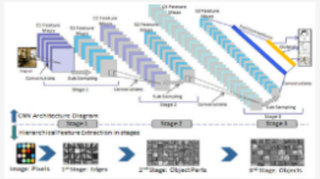
多模态观察空间



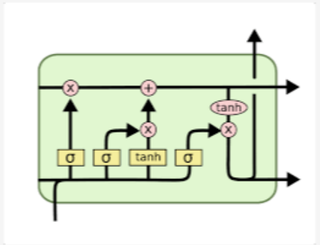


表征编码器（Encoder）

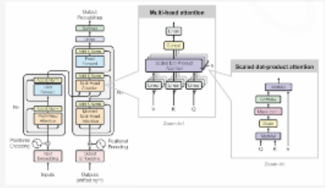
Convolution



LSTM



Transformer



决策预测器（Head）

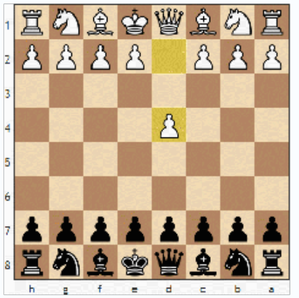
- 离散动作预测
- 连续动作回归
- 连续动作重参数化
- 多维离散
- 层次结构化动作
- 自回归预测

复杂动作空间

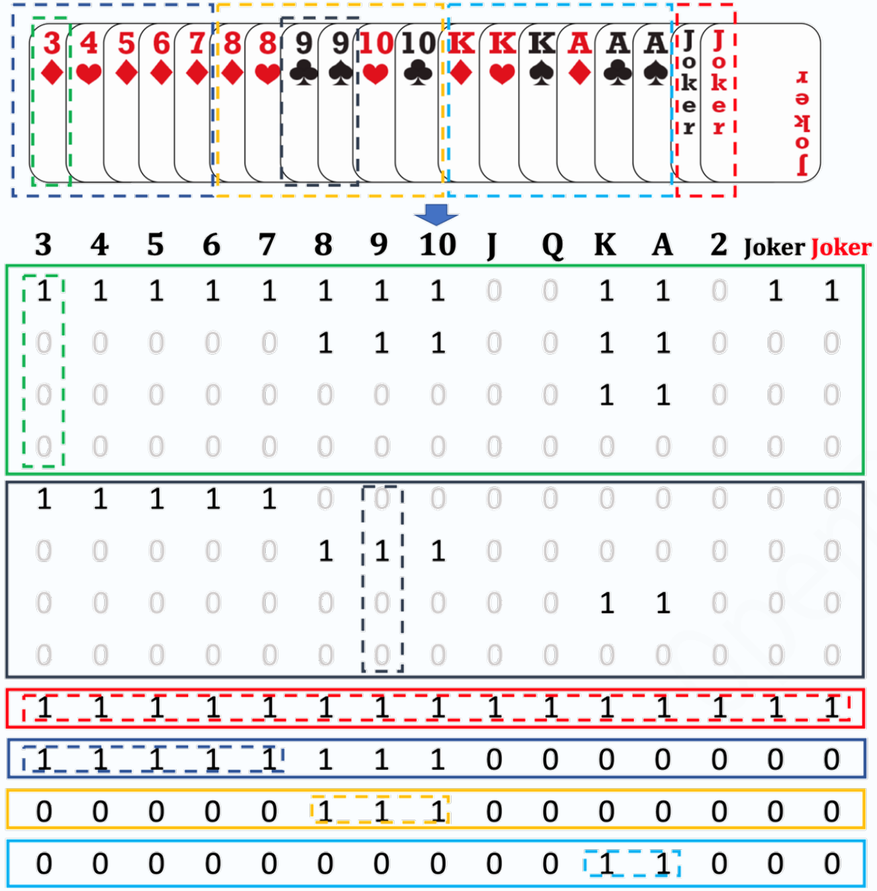
Turn Right

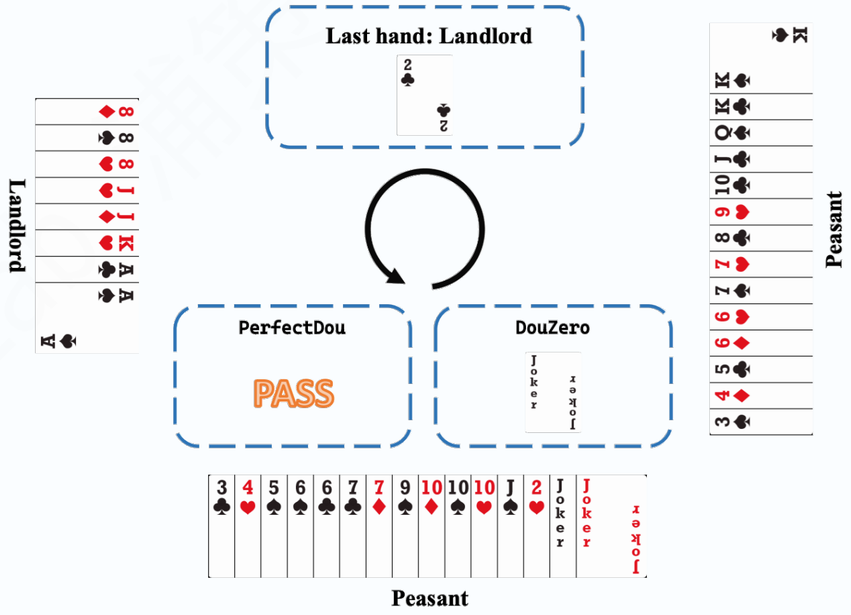
Shoot

Move



向量观察空间

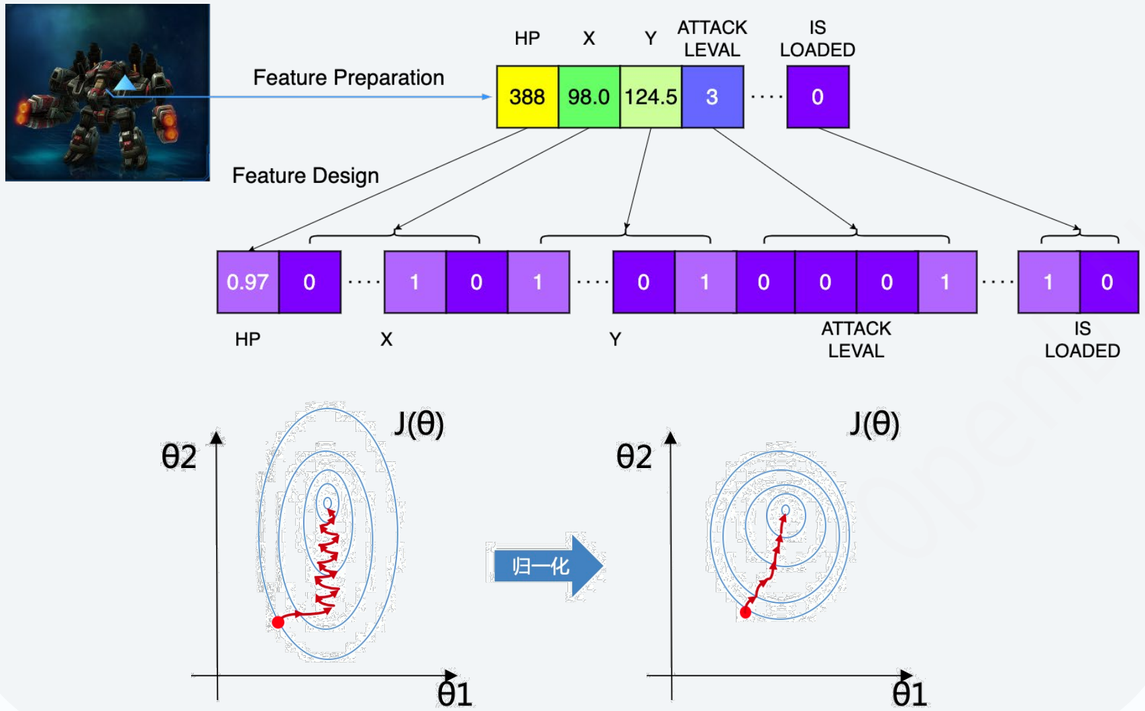




PerfectDou: https://arxiv.org/pdf/2203.16406.pdf

理论：PPO+向量观察预处理

统一量纲



编码设计

One-hot encoding

Color
can
I
eat
the
pizza

One-hot encoding

d0	d1	d2	d3	d4
1	0	0	0	0
0	0	1	0	0
0	1	0	0	0
0	0	0	0	1
0	0	0	1	0

Word Embedding

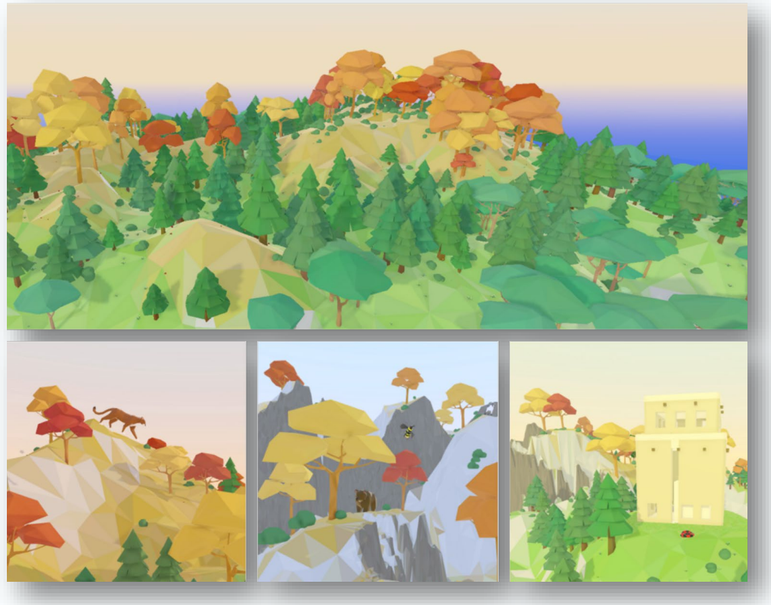
Color
Man
Woman
King
Queen
Orange
Apple
...

Word Embedding

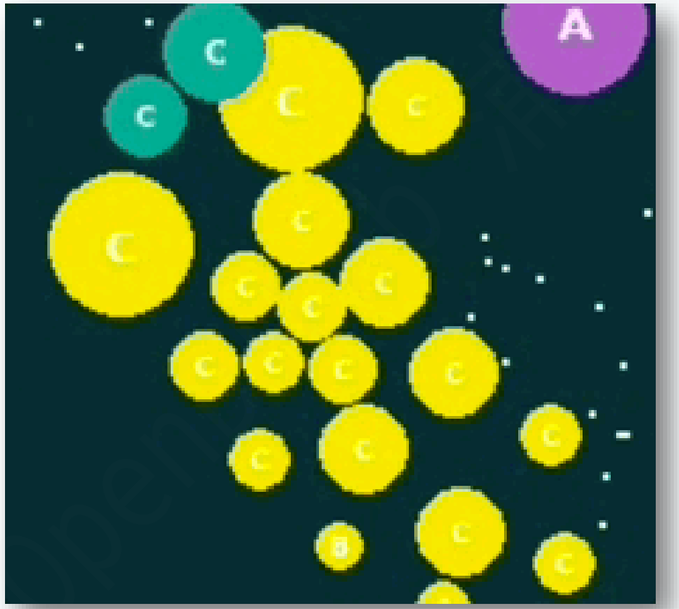
d0	d1	d2	d3	d4
-1.00	0.01	0.03	0.04	0
1.00	0.02	0.02	0.01	0
-0.95	0.93	0.70	0.02	0
0.97	0.95	0.69	0.01	0
0.00	-0.01	0.03	0.95	0
0.01	0.00	-0.02	0.97	0
...	...	...	...	...

理论：PPO+向量观察 不变性

平移不变性



旋转不变性



排列不变性

不变性（invariance） $F(X)=F(T(X))$

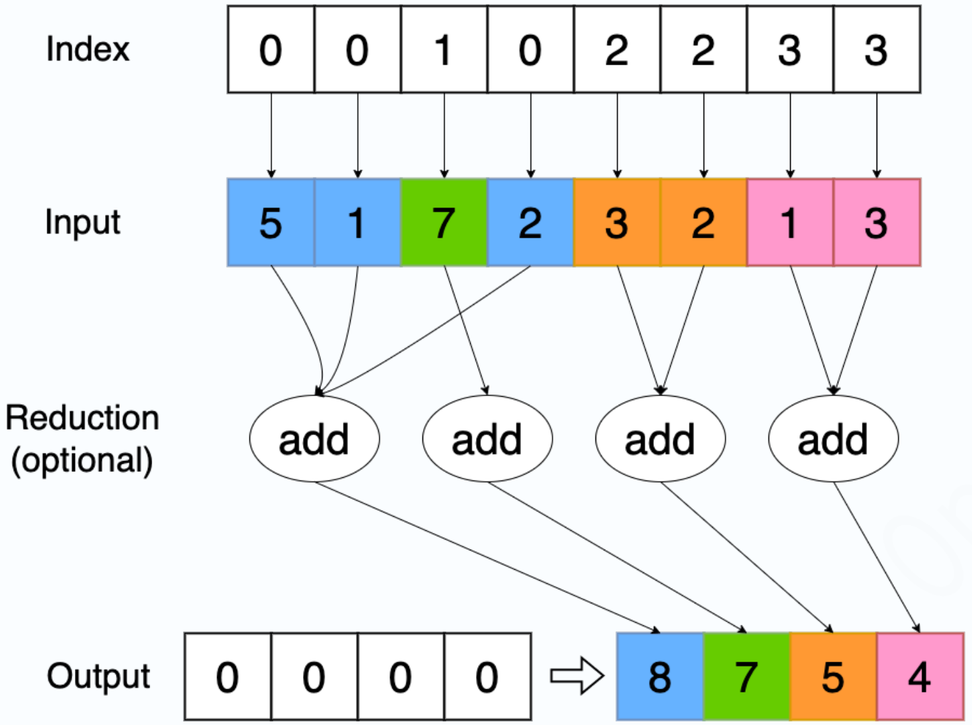
等变性（equivariance） $T(F(X))=F(T(X))$

F指特征编码或神经网络，T指变换，例如平移，旋转，改变顺序

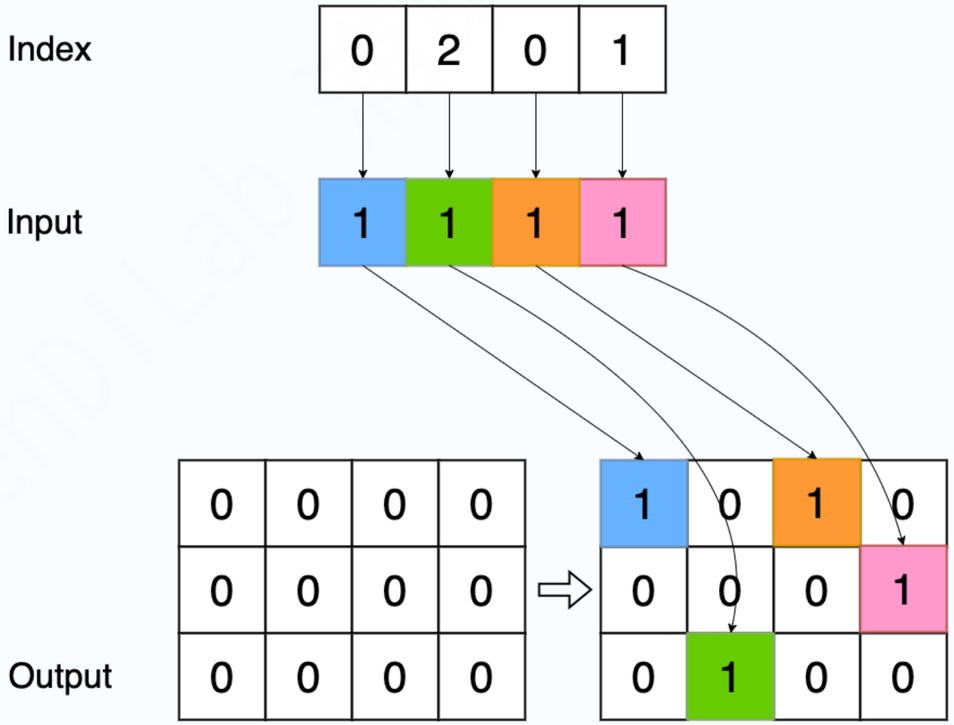
GoBigger: https://github.com/opendilab/GoBigger
ACE + SMAC: https://github.com/opendilab/ACE

代码：特征工程中的张量操作技巧

Scatter: $\text{out}_i = \text{out}_i + \sum_j \text{in}_j$



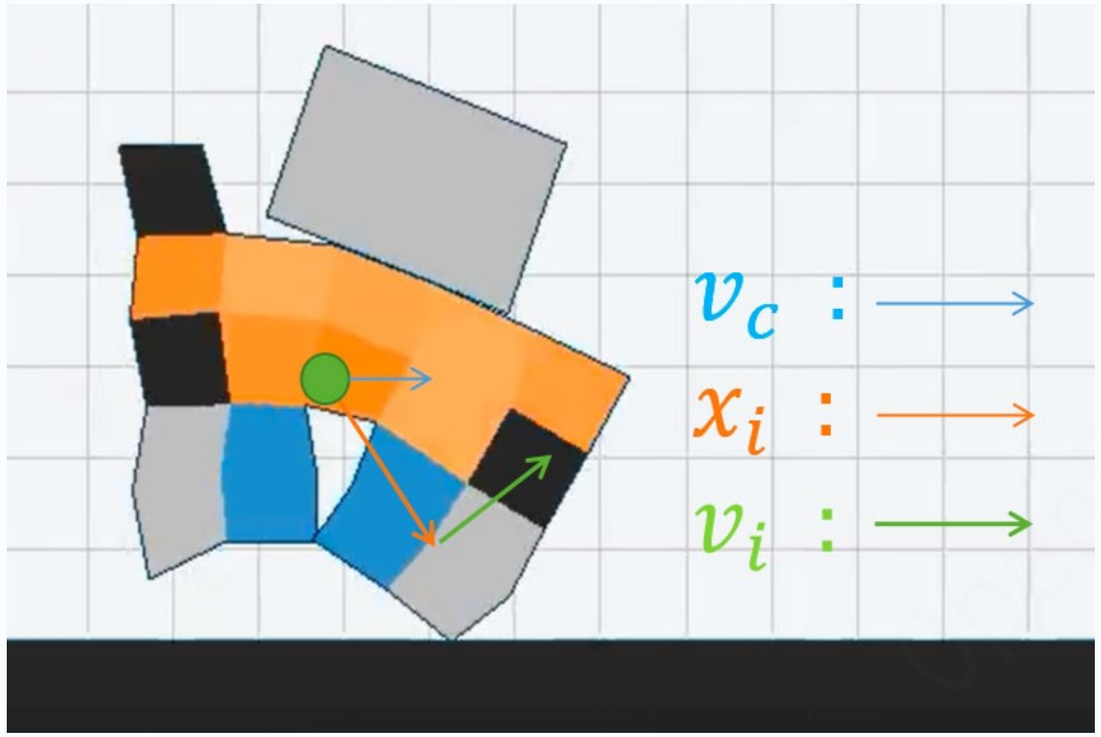
One-Hot Encoding By Scatter

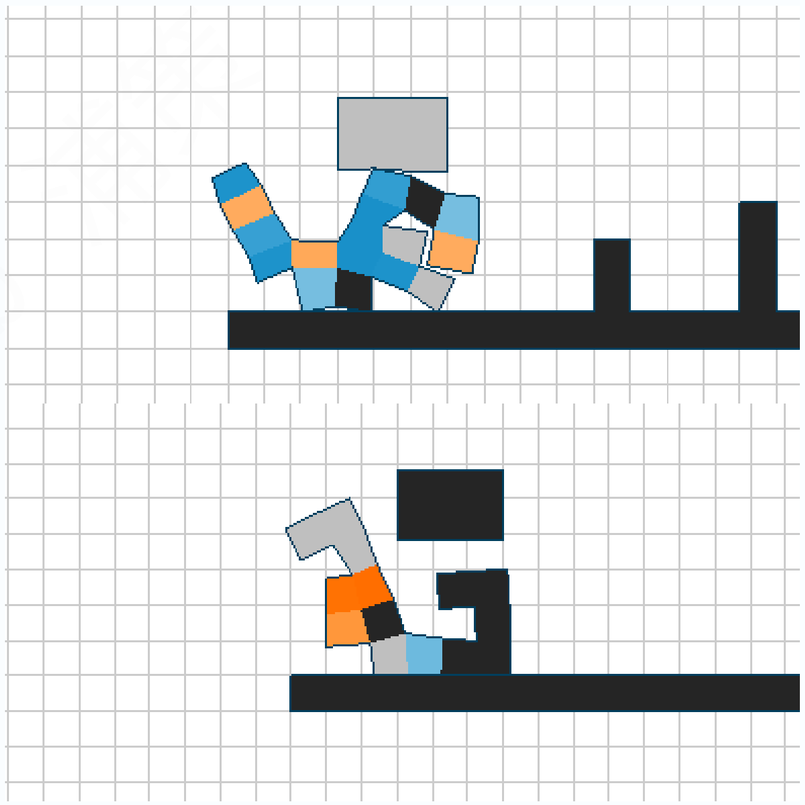


Scatter: https://github.com/rusty1s/pytorch_scatter

完整示例：https://opendilab.github.io/PPOxFamily/

实践：PPO+软体机器人



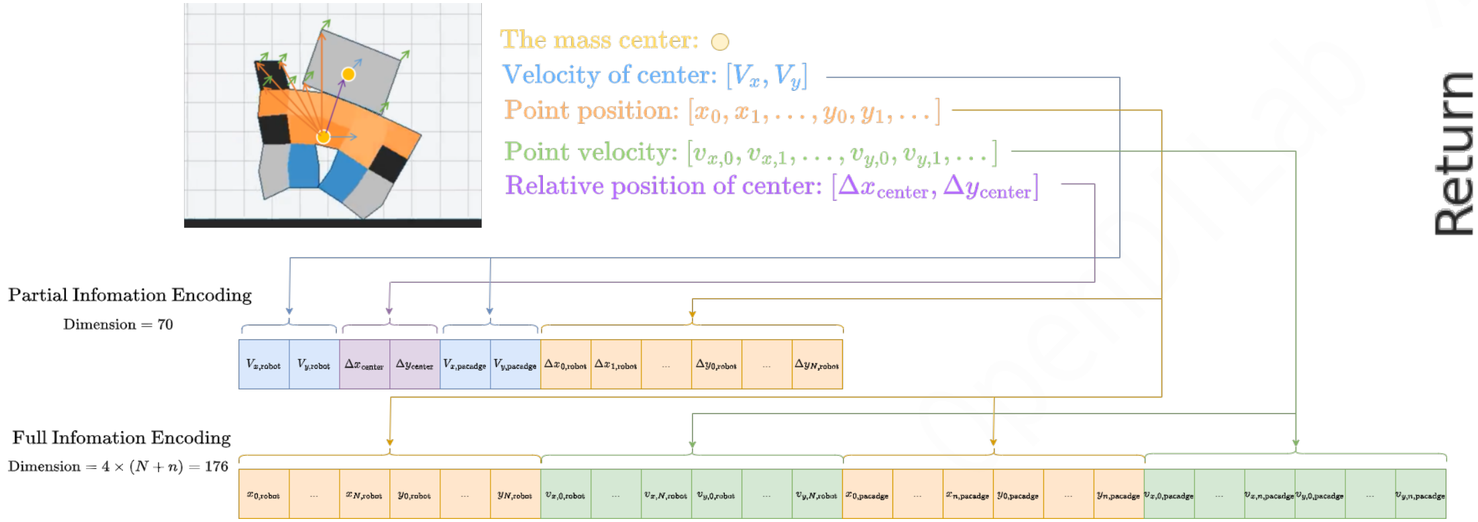


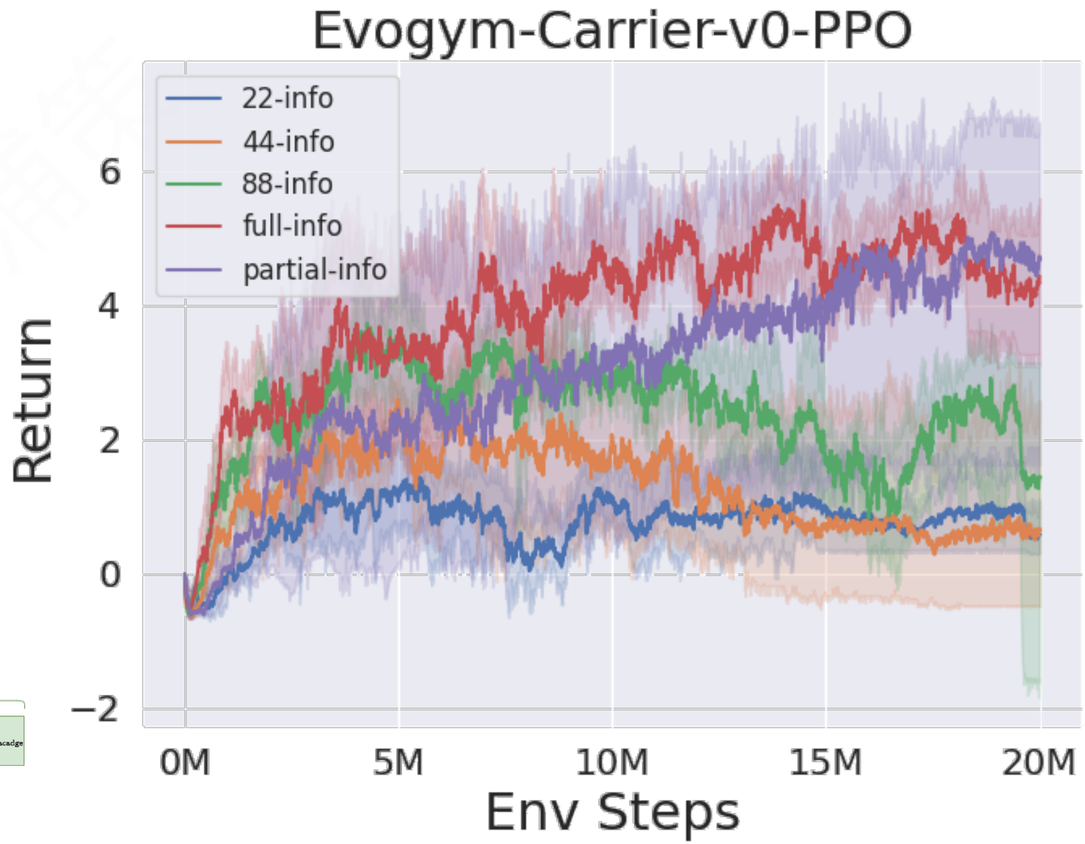
Evogym: https://github.com/EvolutionGym/evogym
DI-engine + Evogym doc: https://di-engine-docs.readthedocs.io/en/latest/13_envs/evogym.html

实践：PPO+软体机器人

观察空间：

机器人全局和局部信息（例如位置，速度）**的编码**

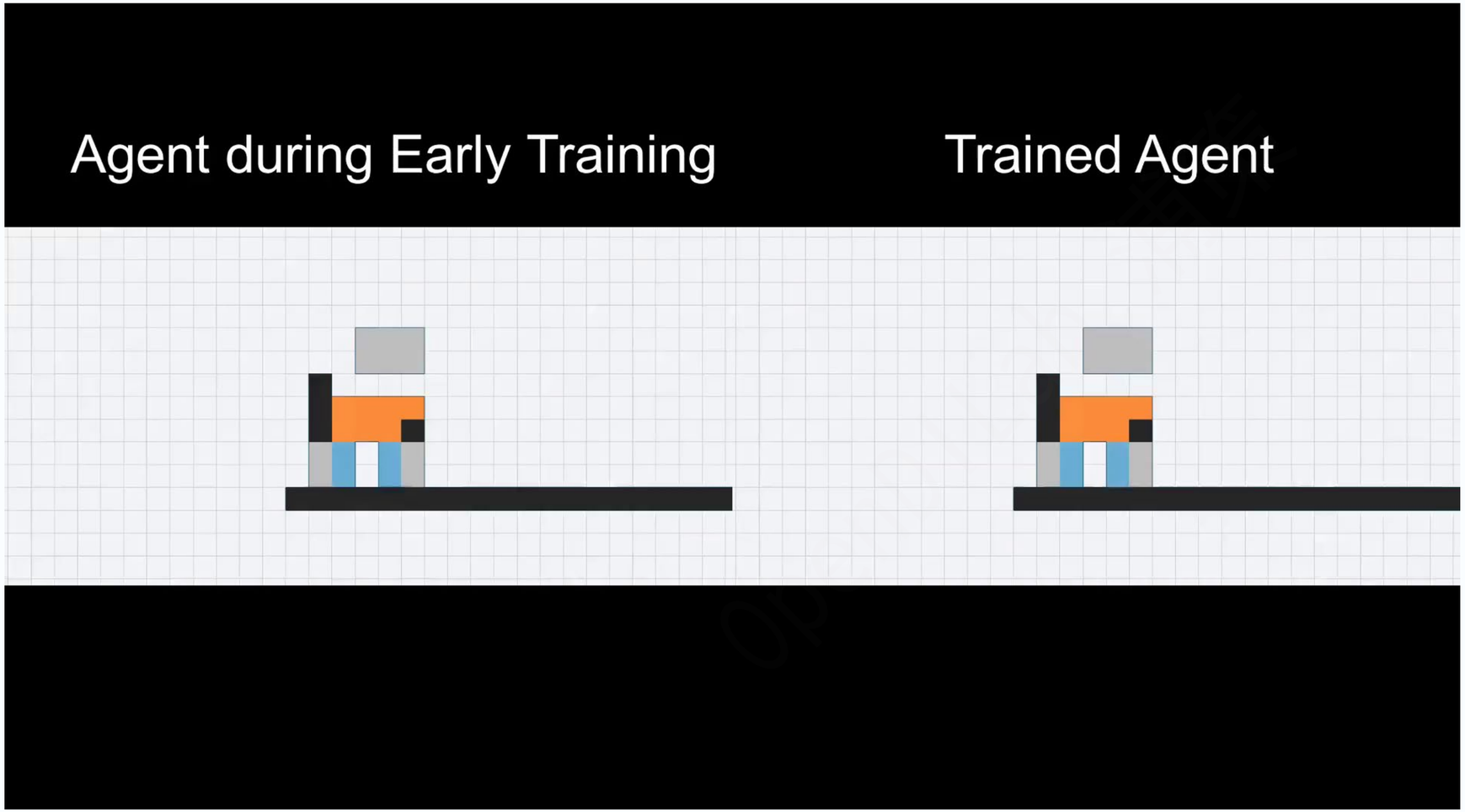




实验细节：https://github.com/opendilab/PPOxFamily/issues/8

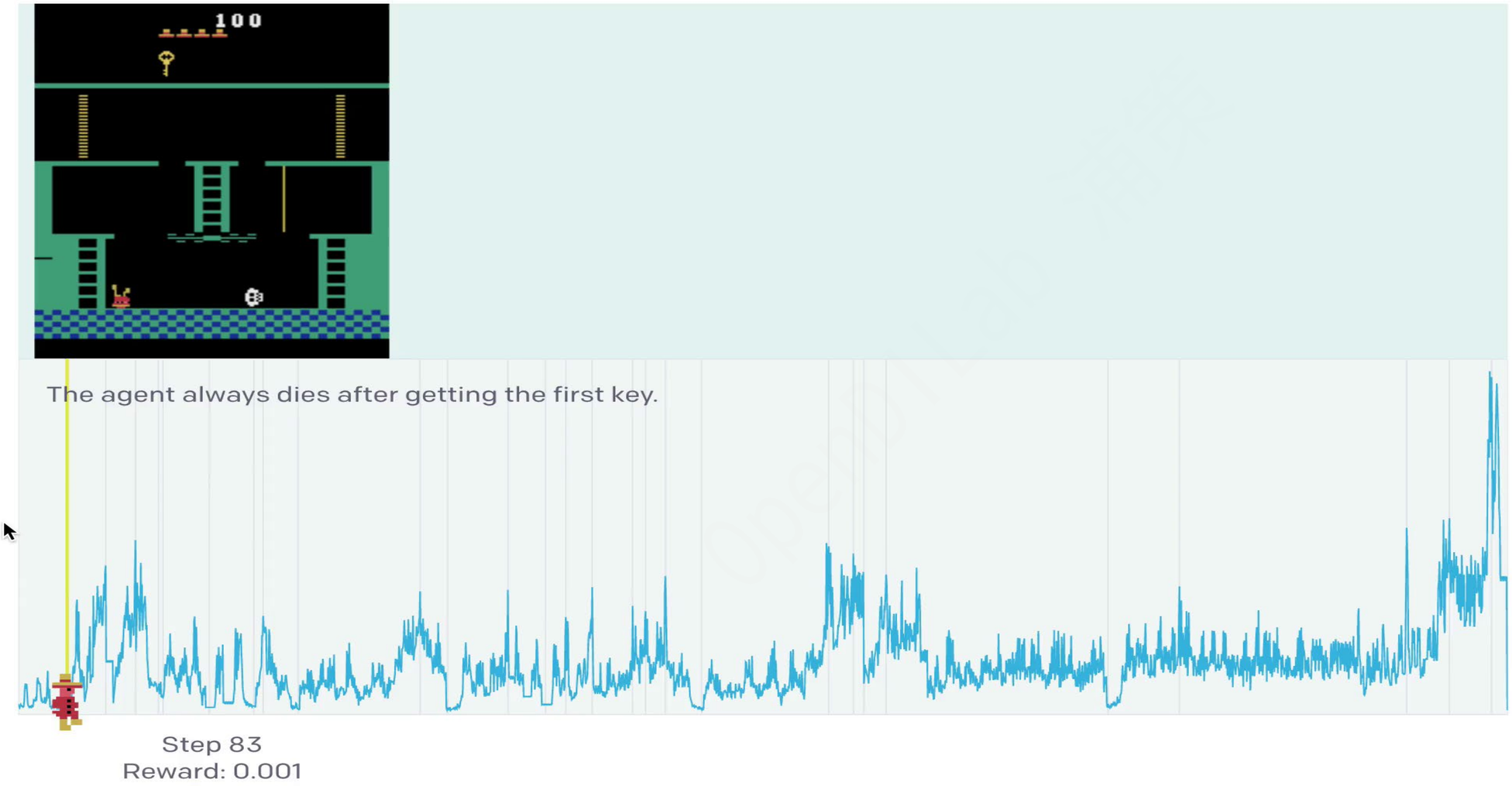
P.S. 88/44/22实验组指只选取软体机器人中部分数量小块的观察信息，数字代表数量

实践：PPO+软体机器人



视频样例：https://github.com/opendilab/PPOxFamily/issues/8

图片观察空间



RND: https://openai.com/blog/reinforcement-learning-with-prediction-based-rewards/

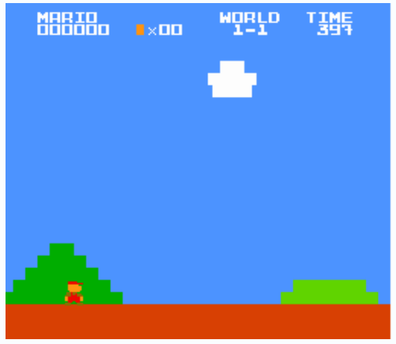
理论：PPO+图片观察预处理

问题：图片数据维度很高但有很多冗余，因此信息密度很低，

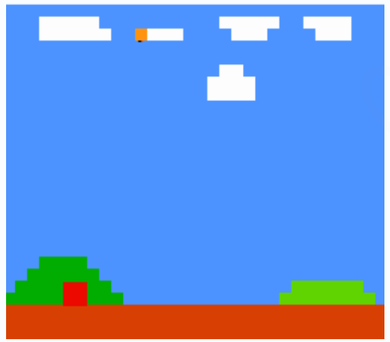
Origin

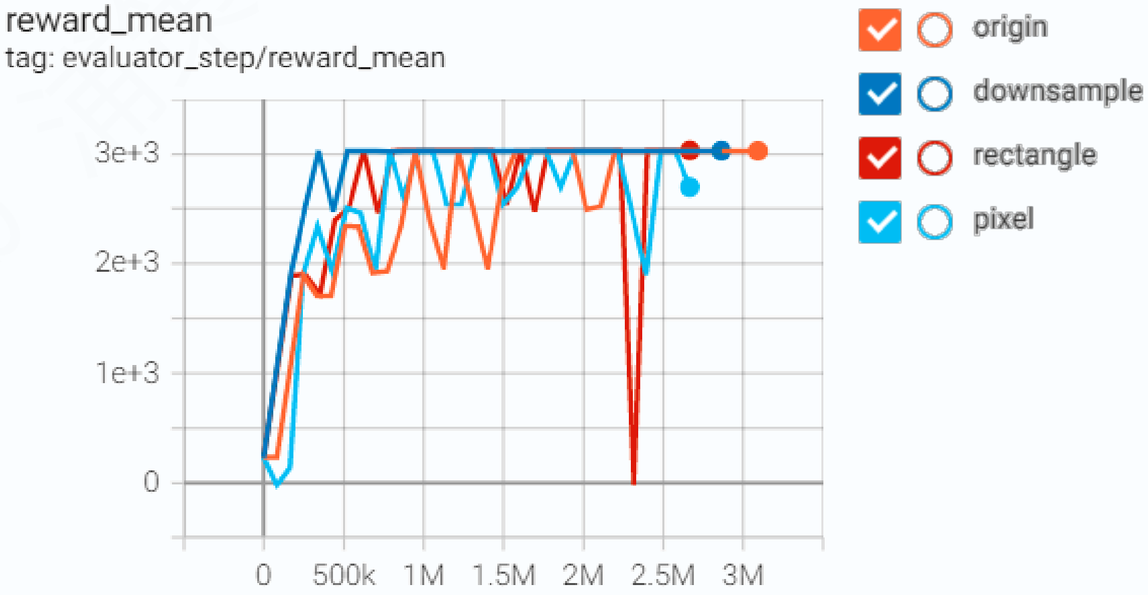
Downsample

Pixel



Rectangle





downsample > pixel >= rectangle >= origin

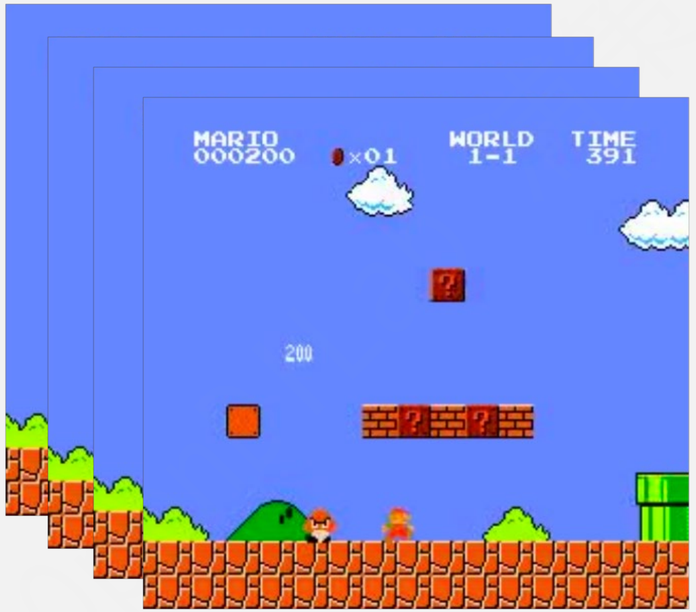
Super Mario Bros: https://github.com/Kautenja/gym-super-mario-bros
DI-engine + Mario Doc: https://di-engine-docs.readthedocs.io/zh_CN/latest/13_envs/gym_super_mario_bros_zh.html
GradCAM: https://github.com/frgfm/torch-cam

理论：PPO+图片观察 运动信息

单帧

State Shape: (1, 84, 84)

叠帧



State Shape: (4, 84, 84)

光流

State Shape: (3, 84, 84)

问题：单帧图片无法表示运动信息（例如方向，速度）

解决思路：堆叠连续4帧环境帧为一个动作帧 or 提取光流

Optical Flow: https://en.wikipedia.org/wiki/Optical_flow

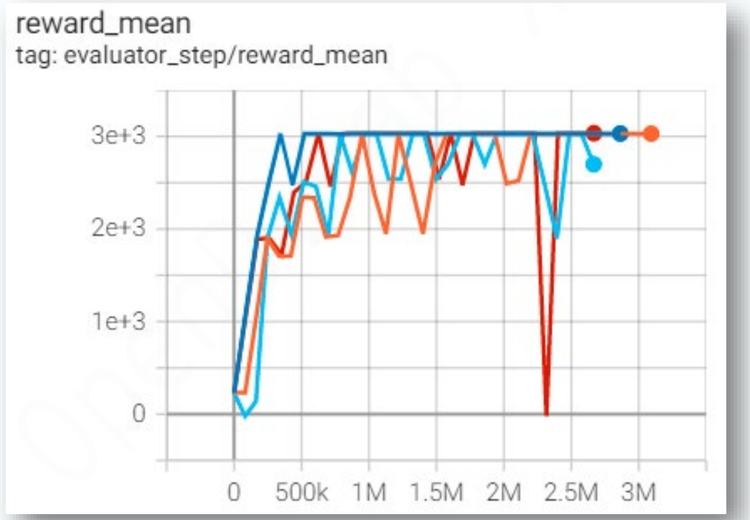
P.S. 运动信息问题进一步延伸可以拓展到 POMDP，相关内容将会在课程第五讲详细展开

理论：PPO+图片观察 运动信息

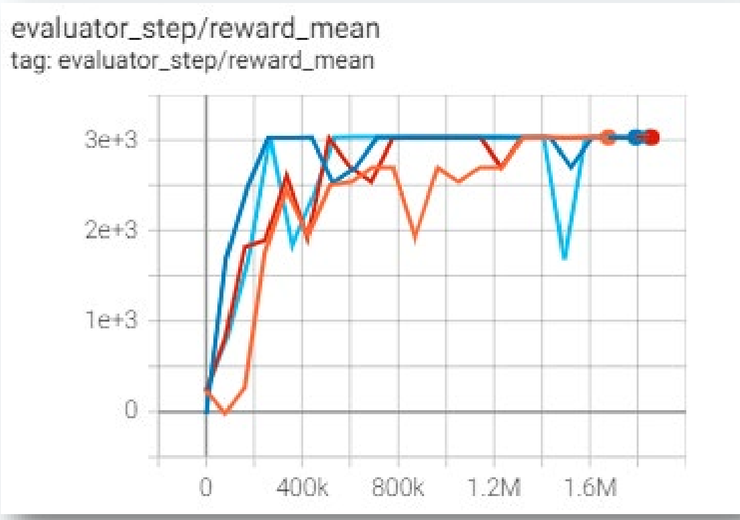
origin
downsample
rectangle
pixel

单帧

叠帧

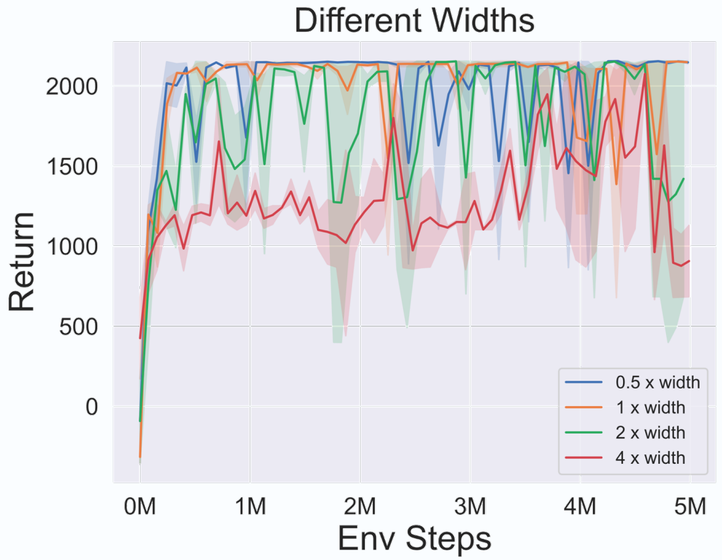


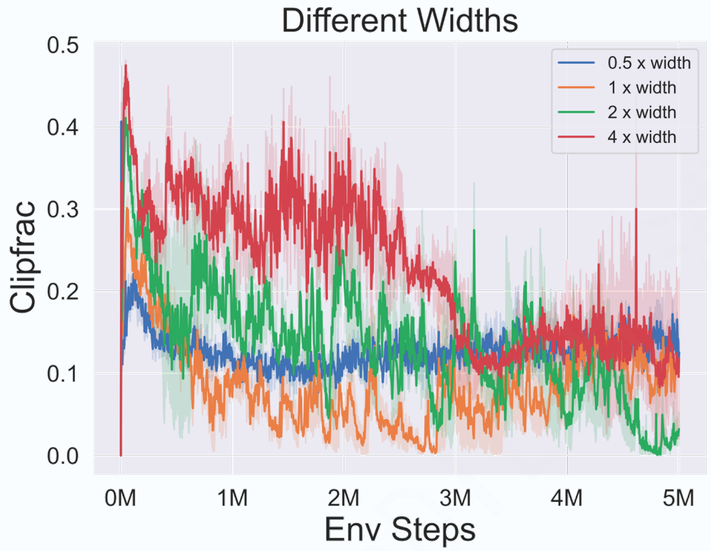
光流

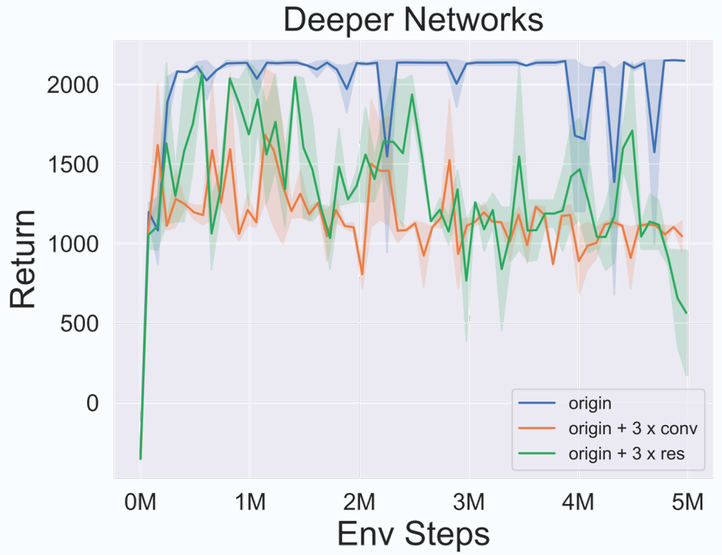


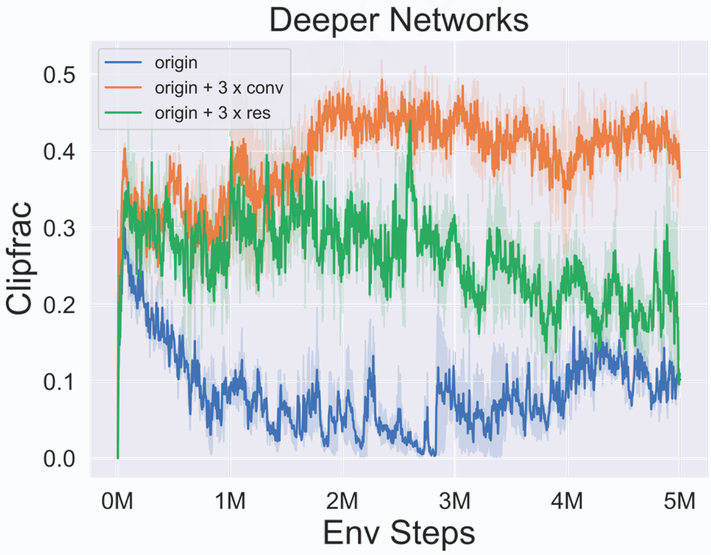
实验细节：https://github.com/opendilab/PPOxFamily/issues/8

理论：PPO+图片观察 网络架构







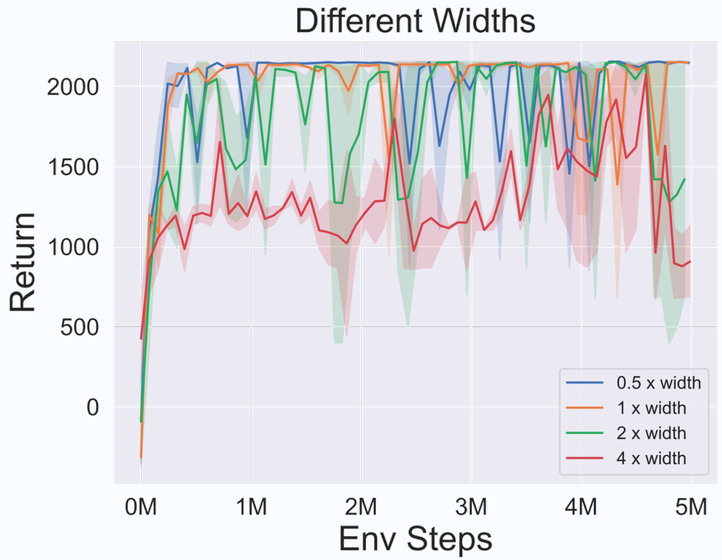


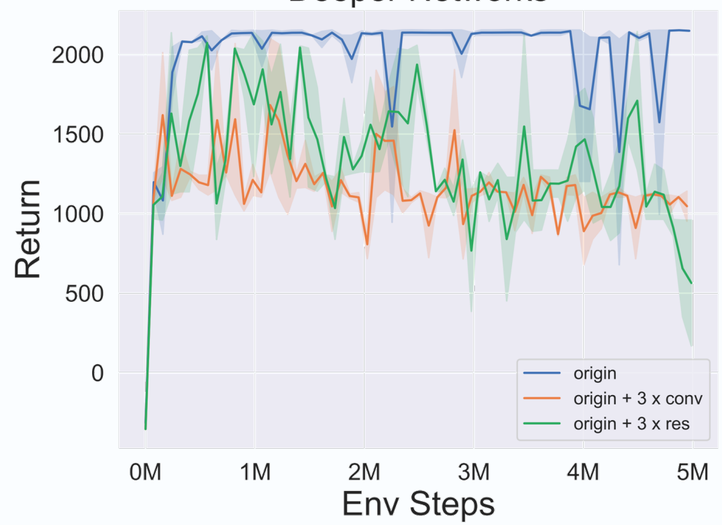
Key Facts:

- 单纯的加深 or 加宽网络并不总是有效的

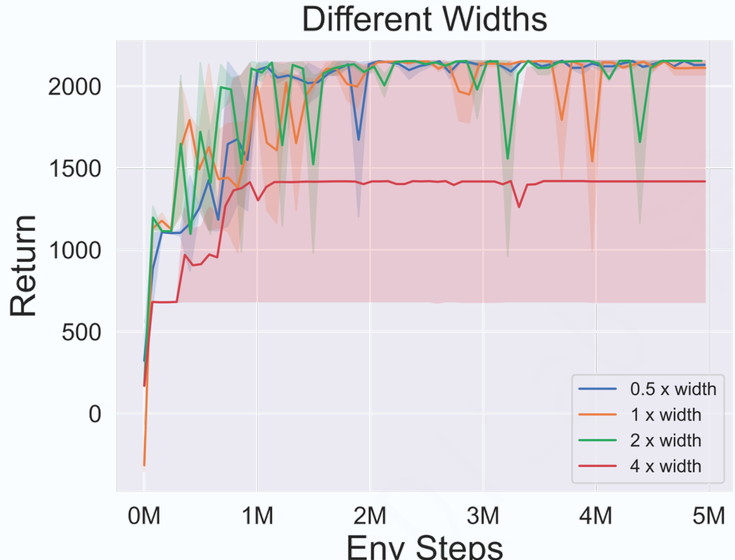
理论：PPO+图片观察 网络架构

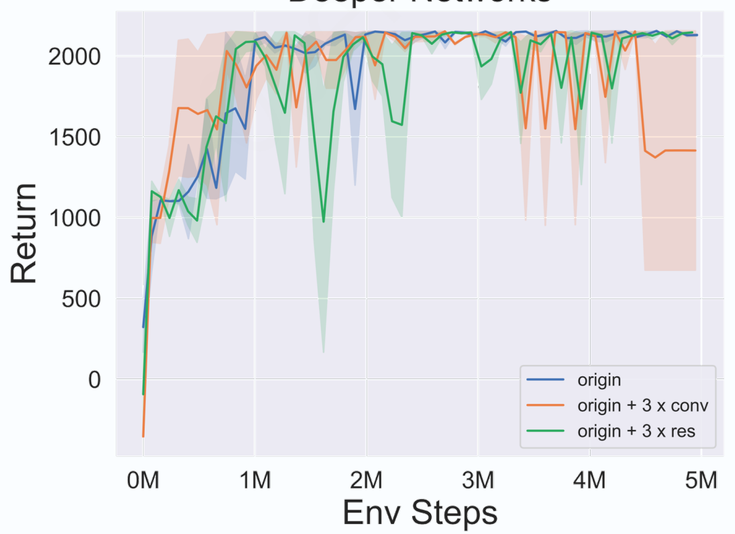
without LN





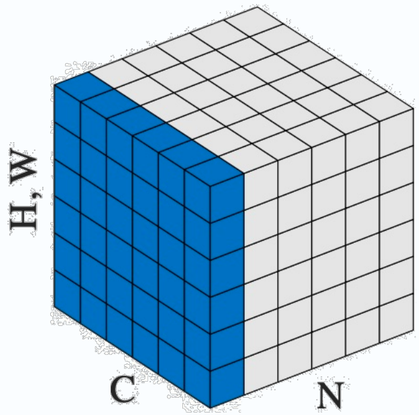
with LN





Key Facts:

- 网络一旦变大，就需要类似 LN 这样的模块来稳定训练



代码：巧用 Env Wrapper

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View code on GitHub

PyTorch 代码实现：用于 PPO 训练的超级马里奥兄弟仿真环境设置

Related Link

概述

创建超级马里奥环境，并使用一系列 Env Wrapper 来实现各种预处理变换

```python
from ding.envs import DingEnvWrapper
from ding.envs.env_wrappers import MaxAndSkipWrapper, WarpFrameWrapper, ScaledFloatFrameWrapper, FrameStackWrapper, \
    EvalEpisodeReturnEnv
import gym_super_mario_bros
from nes_py.wrappers import JoypadSpace


def wrapped_mario_env():
```

转换为 DI-engine 的环境接口格式

```python
    return DingEnvWrapper(
```

将动作空间简化为2维的离散空间（向右走，向右上跳）

```python
        JoypadSpace(gym_super_mario_bros.make("SuperMarioBros-1-1-v0"), [["right"], ["right", "A"]]),
```

添加各类 Env Wrapper 的相关配置

```python
        cfg={
            'env_wrapper': [
```

添加环境帧采样 Wrapper，每隔四帧采样一帧作为智能体的观测信息

```python
                lambda env: MaxAndSkipWrapper(env, skip=4),
```

添加图片格式和尺寸统一化 Wrapper

```python
                lambda env: WarpFrameWrapper(env, size=84),
```

完整示例：https://opendilab.github.io/PPOxFamily/

实践：PPO+超级马里奥

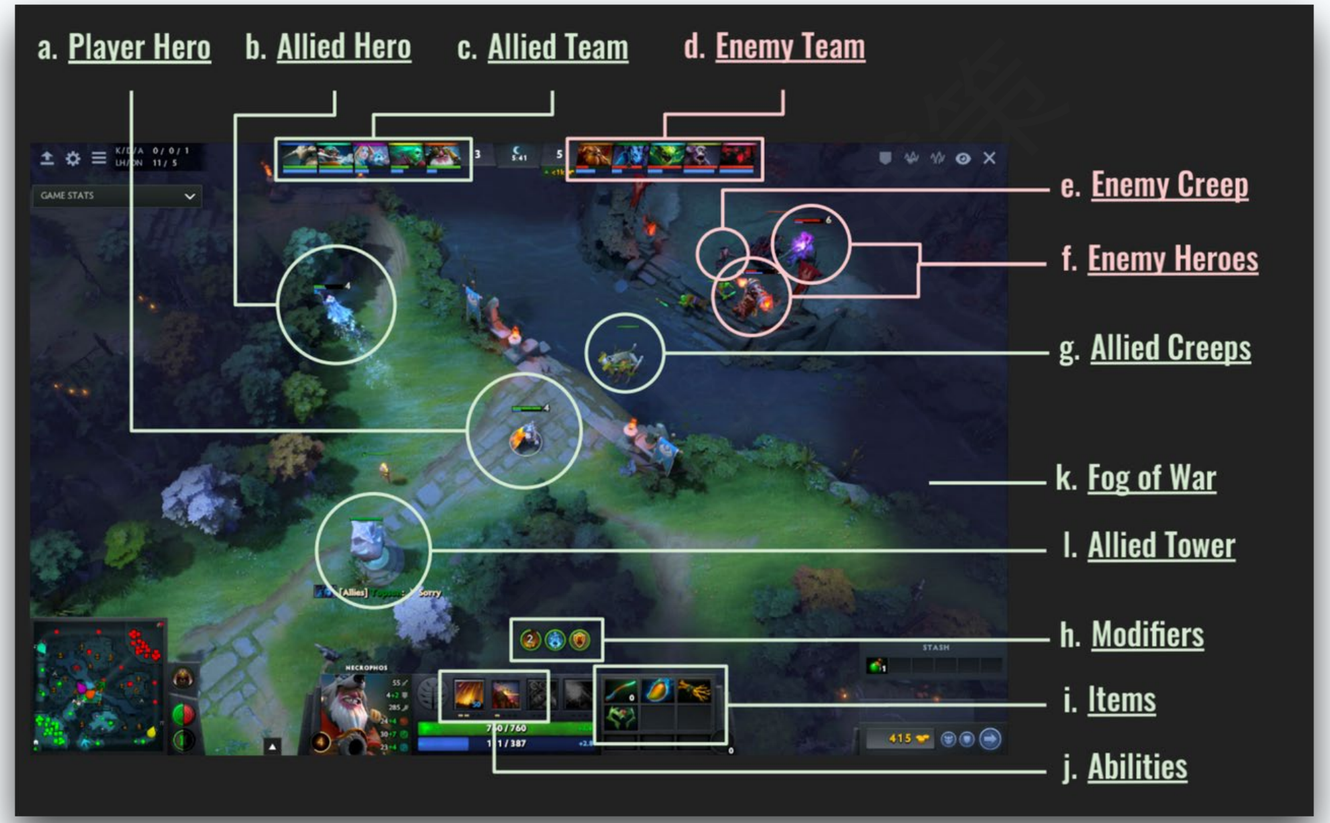
Level 1-1

Level 1-4

Super Mario Bros: https://github.com/Kautenja/gym-super-mario-bros
DI-engine + Mario Doc: https://di-engine-docs.readthedocs.io/zh_CN/latest/13_envs/gym_super_mario_bros_zh.html
视频样例：https://github.com/opendilab/PPOxFamily/issues/8

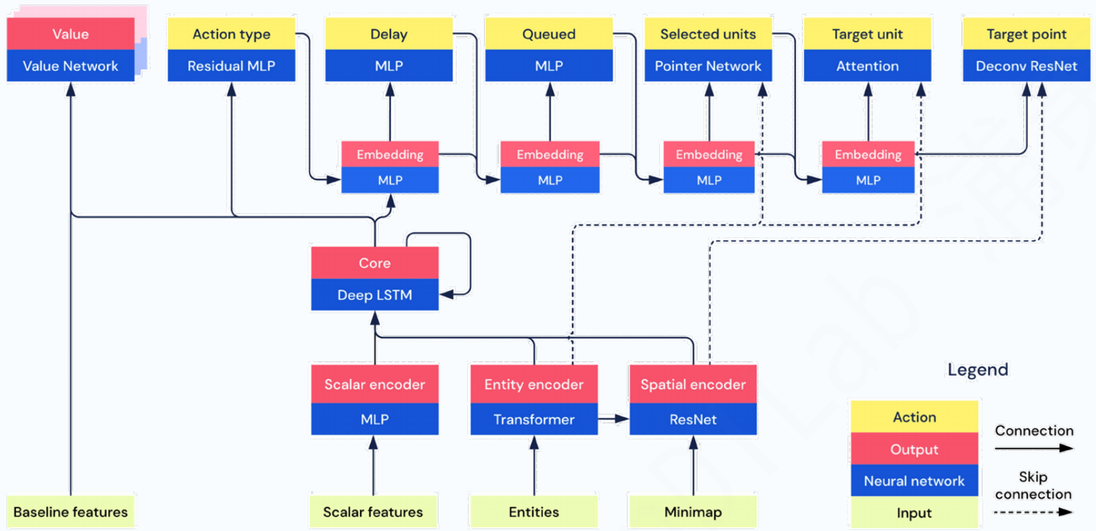
Struct

复杂结构化观察空间



OpenAI Five: https://openai.com/five/

理论：PPO+结构化观察 概述

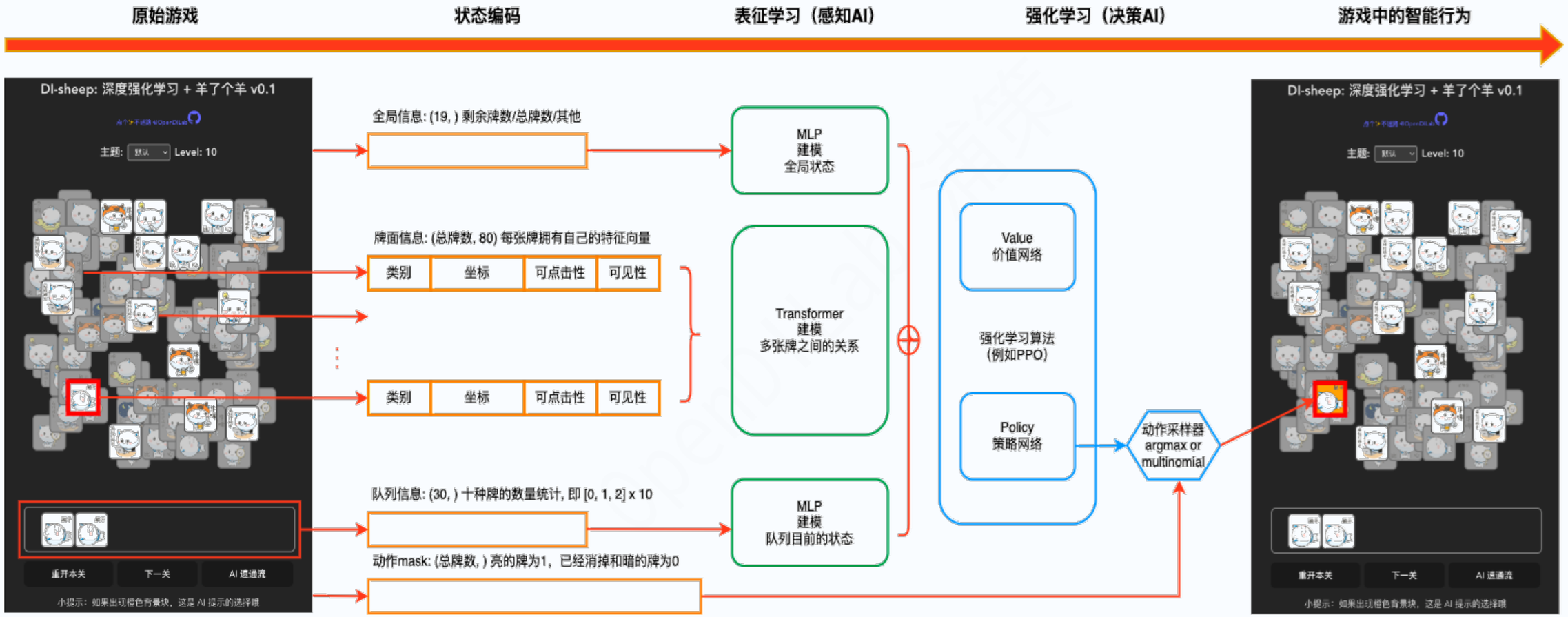


解决方案：

- 不同模态的数据需要结合对应领域经典的建模方法和网络结构设计
- 重要的信息利用 skip connection 进行补充
- 要根据决策任务的特点灵活组合各种网络结构设计方法

AlphaStar: https://www.deepmind.com/blog/alphastar-grandmaster-level-in-starcraft-ii-using-multi-agent-reinforcement-learning

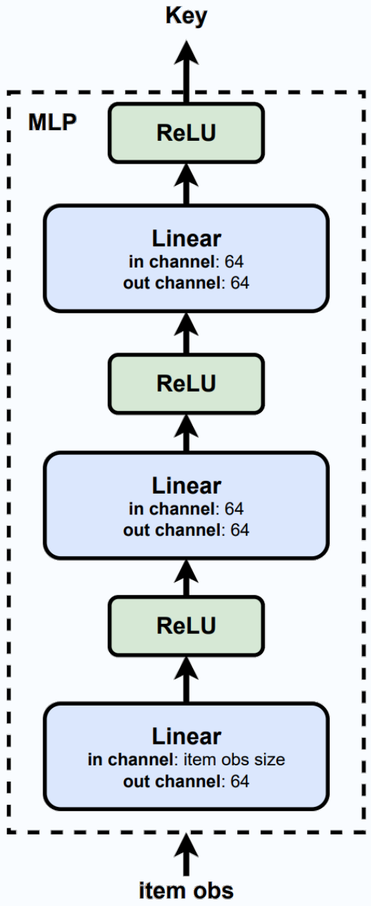
实践：PPO+羊了个羊



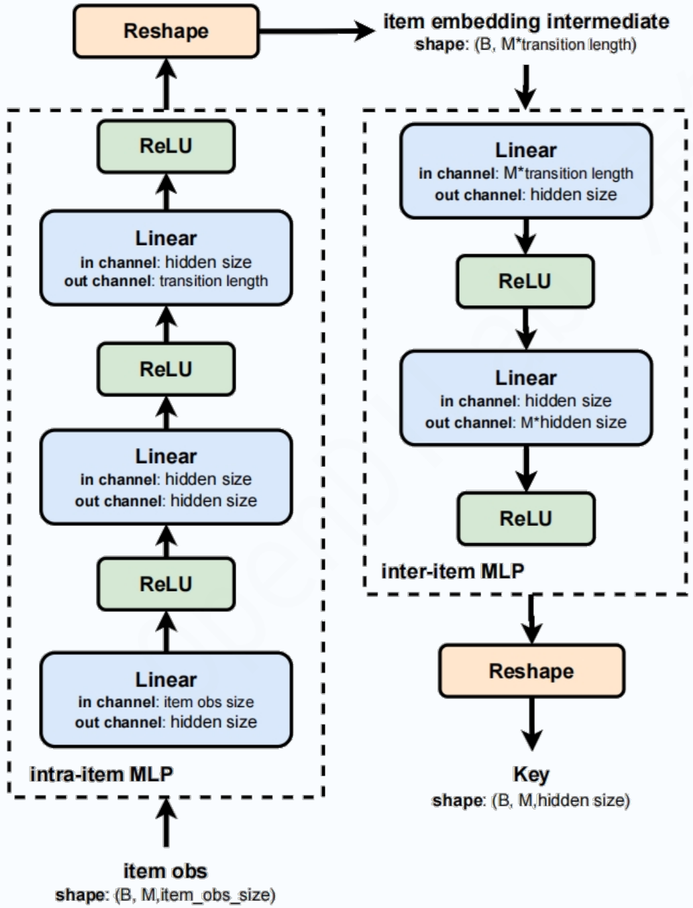
DI-sheep: https://github.com/opendilab/DI-sheep

实践：PPO+羊了个羊

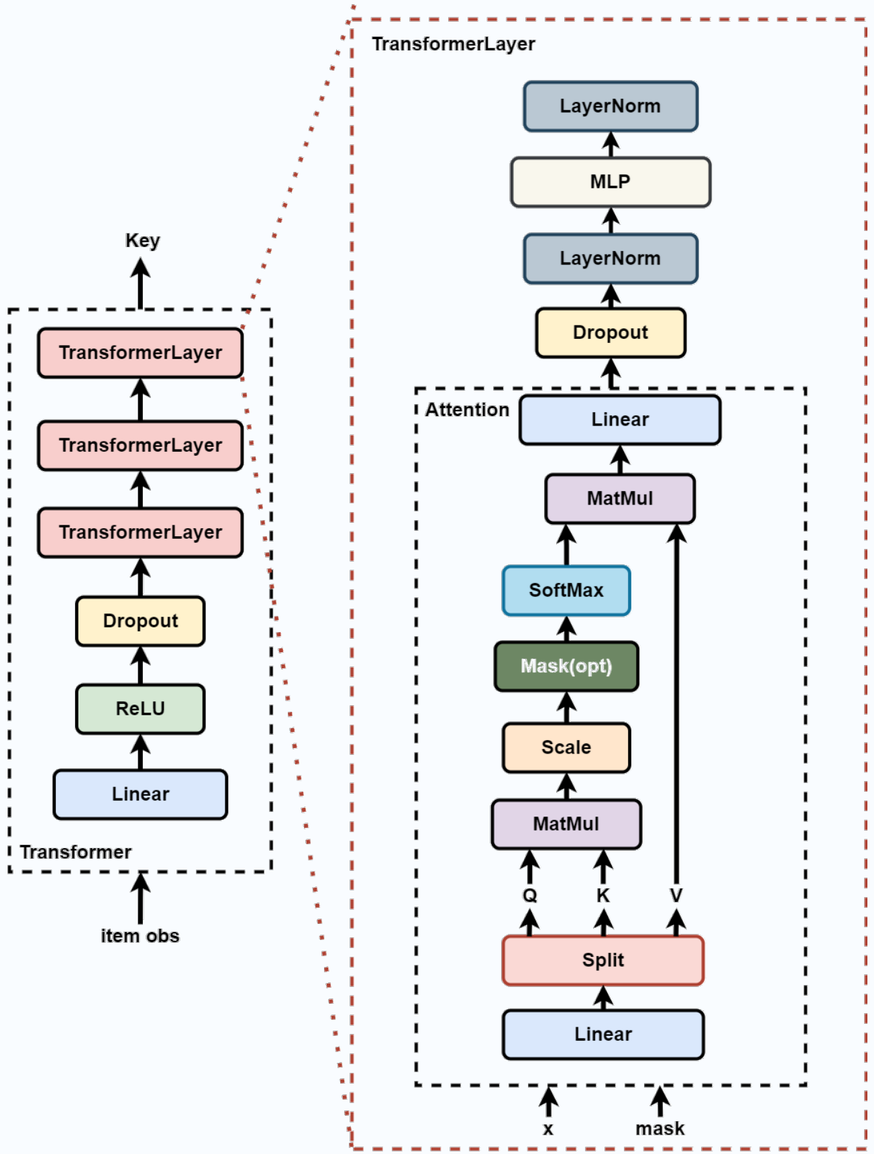
不同的牌面信息编码器



MLP



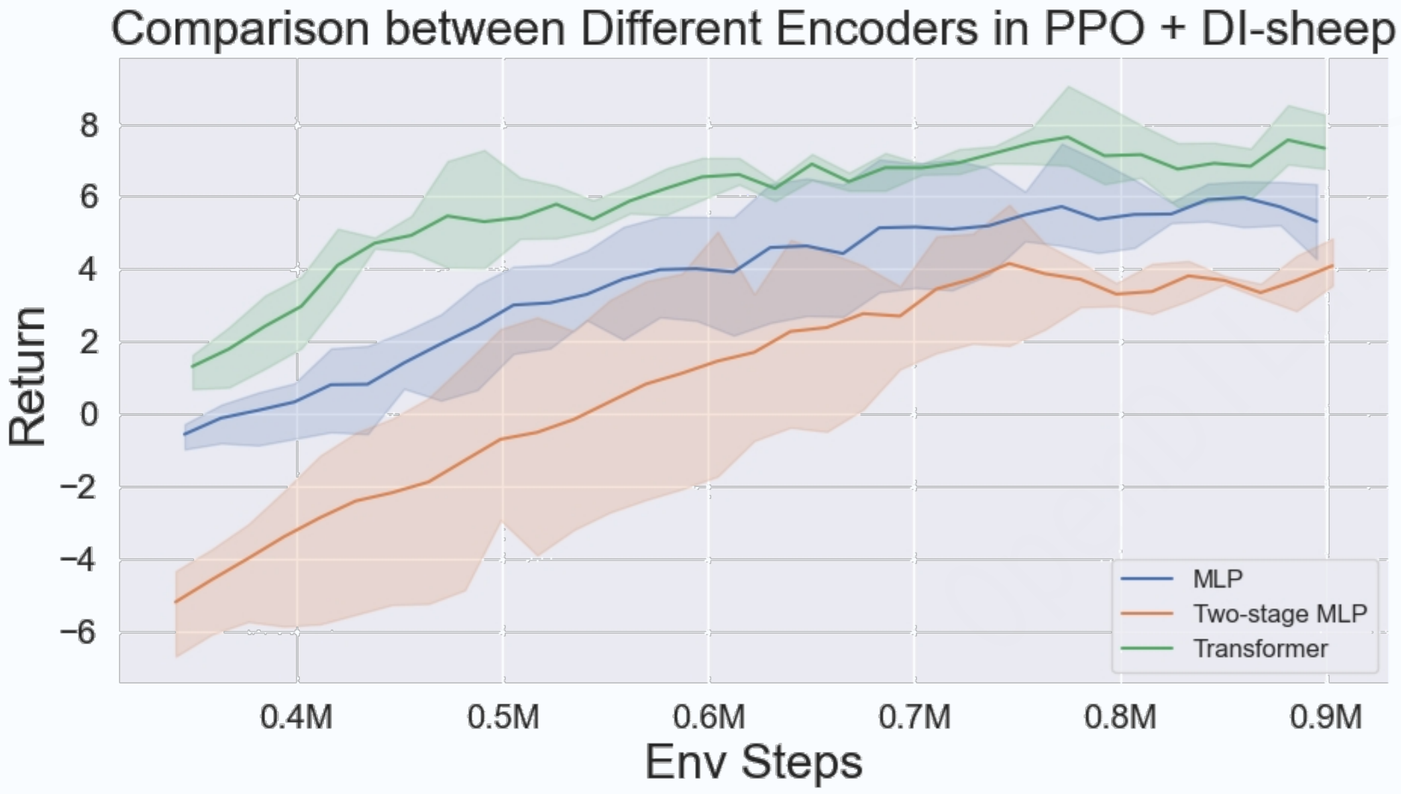
Two-Stages MLP



Transformer

实践：PPO+羊了个羊

（实验对比）不同的牌面信息编码器



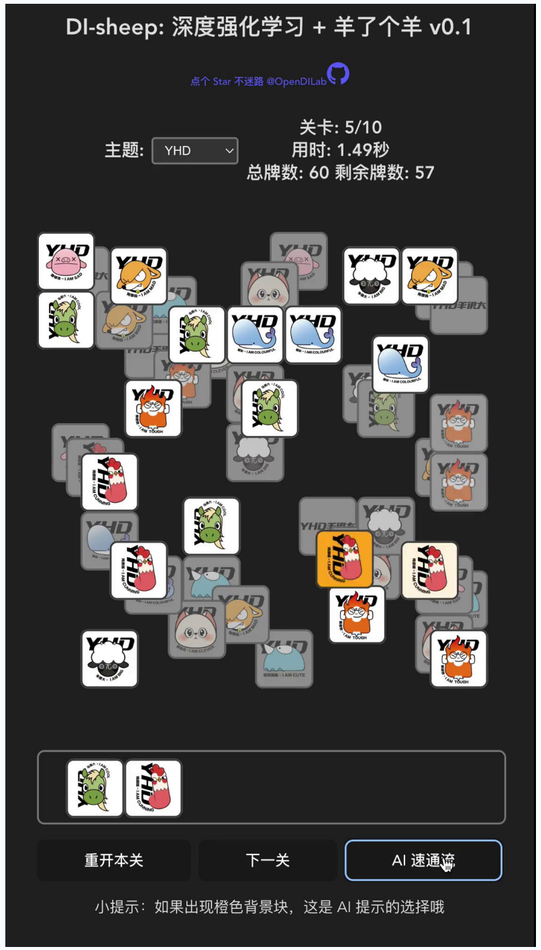
实验细节：https://github.com/opendilab/PPOxFamily/issues/8

Key Facts:

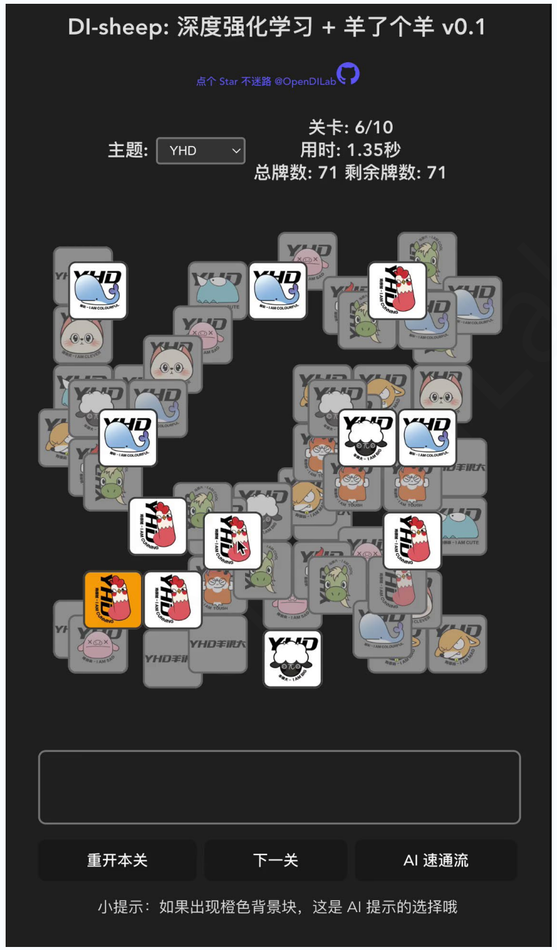
- 环境角度：多张牌之间的关系建模很重要
- 计算角度：参数量大小不一定重要，合理利用参数进行计算很重要
- 算法角度：网络结构的设计代表问题的上限，网络的训练方式决定问题的下限

实践：PPO+羊了个羊

乖巧型



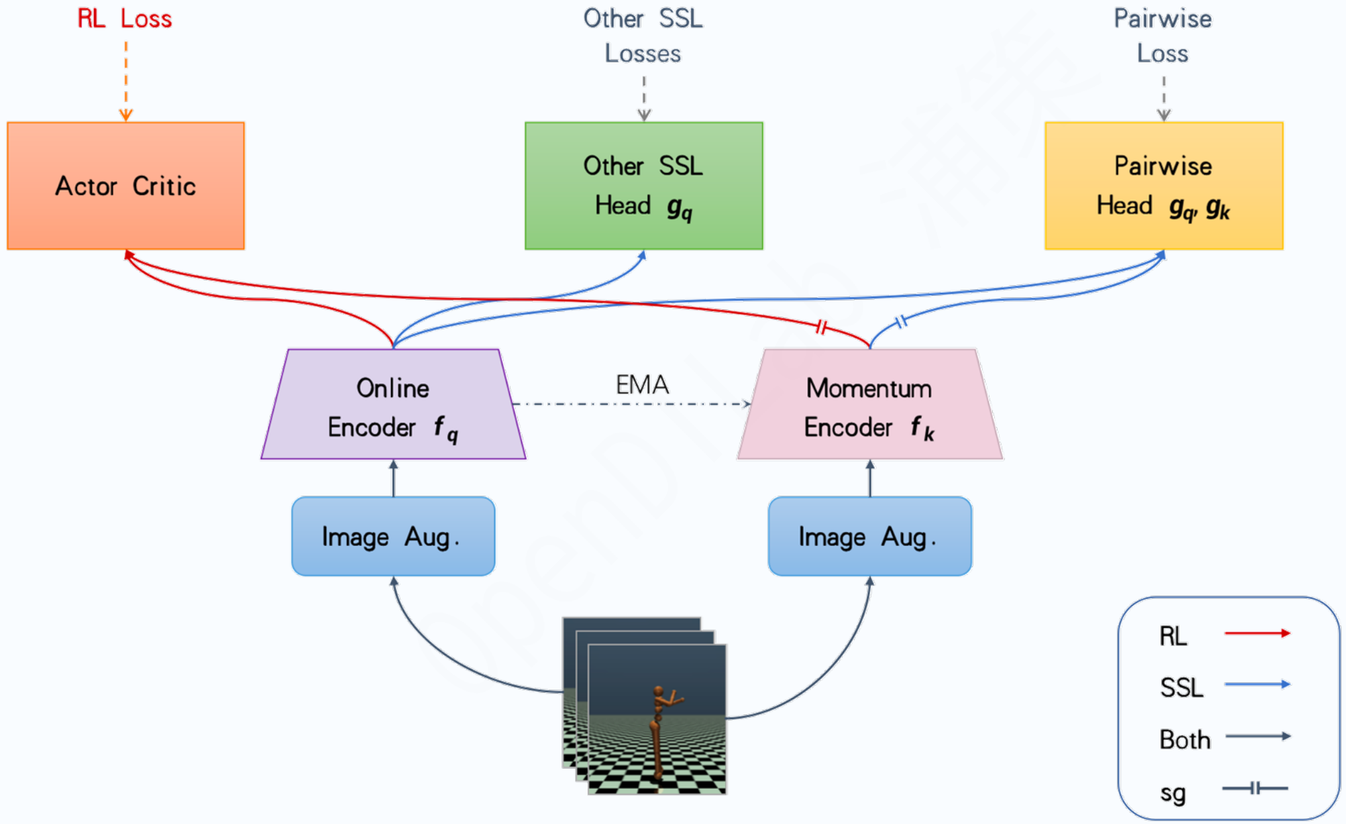
叛逆型



合作型

实验细节：https://github.com/opendilab/PPOxFamily/issues/8 科普文章：https://mp.weixin.qq.com/s/4Z3WtkcWRp6x4x60RVELfQ

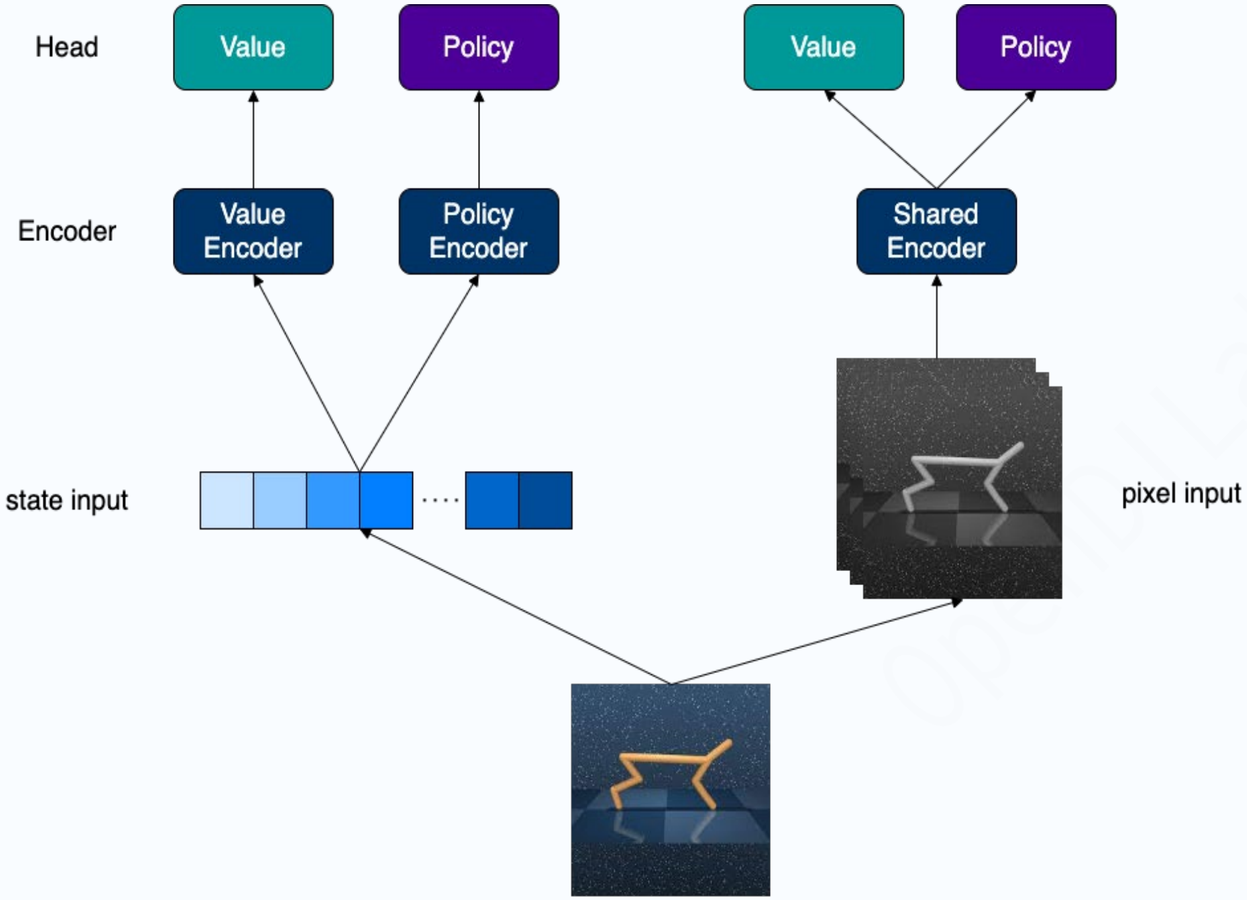
通用观察空间训练方法



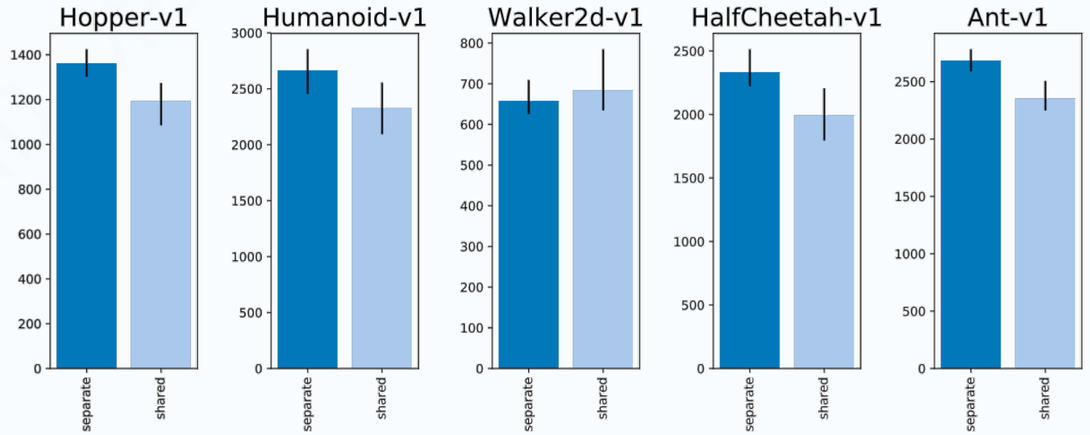
Does Self-supervised Learning Really Improve Reinforcement Learning from Pixels? https://openreview.net/forum?id=fVslVNBfjd8

观察空间表征学习补充材料：https://github.com/opendilab/PPOxFamily/blob/main/chapter3_obs/chapter3_supp_representation.pdf

理论：Actor和Critic是否共享编码器



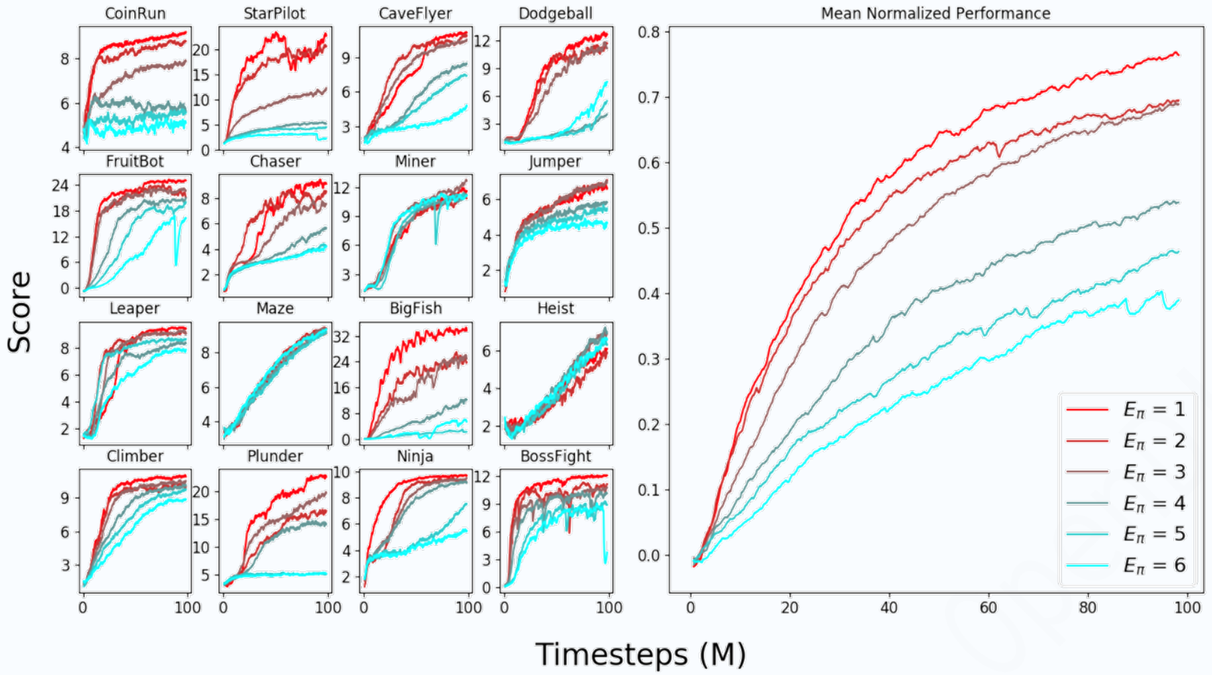
经验原则：高维共享，低维不共享



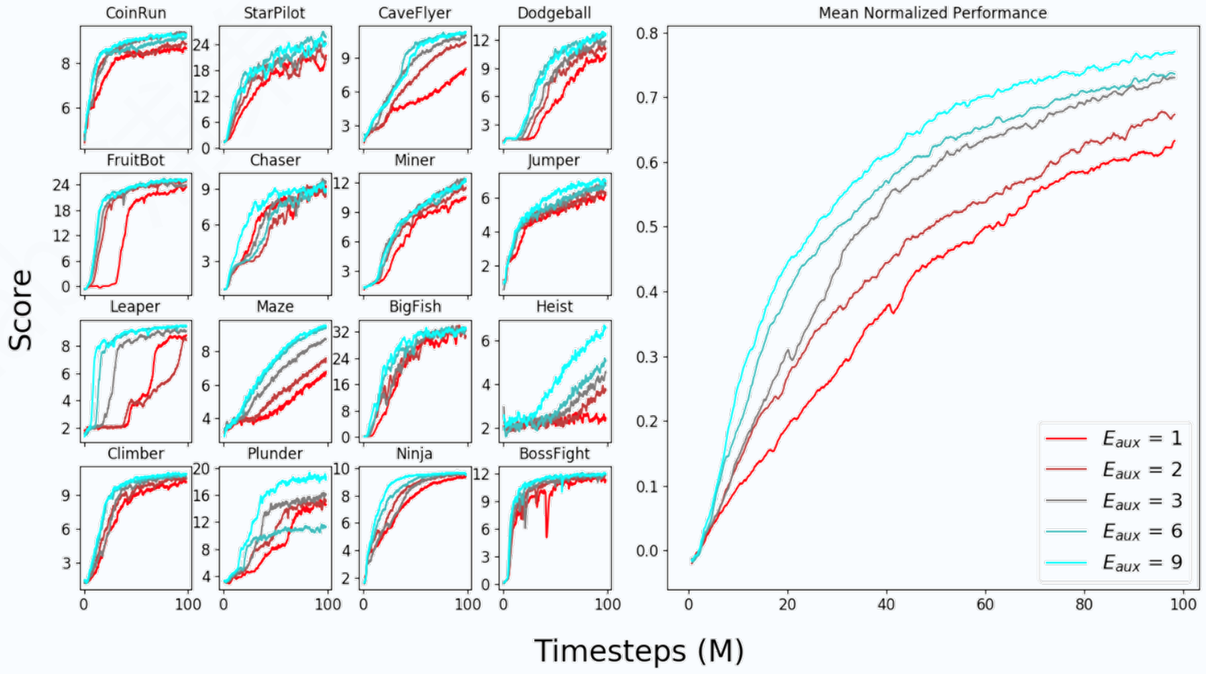
What Matters for On-Policy Deep Actor-Critic Methods? A Large-Scale Study:
https://openreview.net/forum?id=nIAxjsniDzg

理论：Actor和Critic训练的不同特性

Policy Reuse



Value Reuse

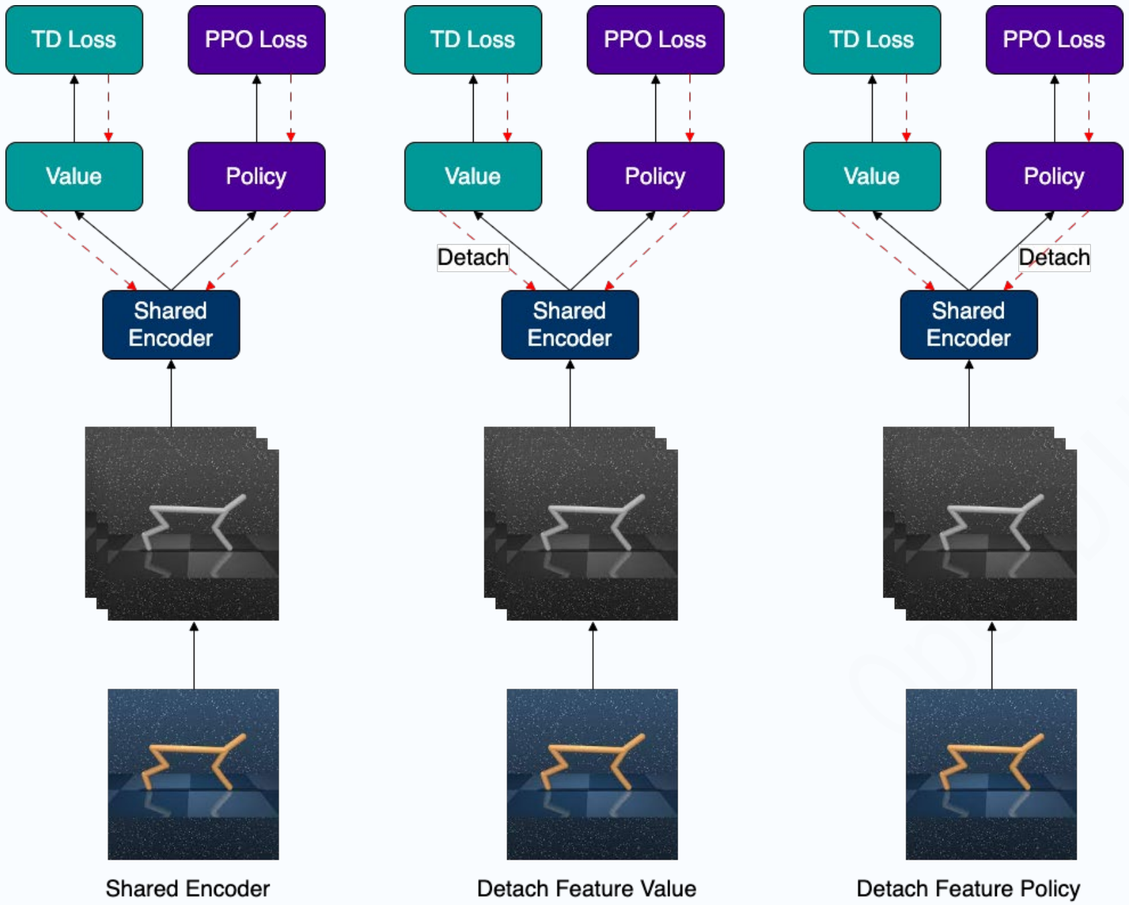


策略函数（Policy）：对数据新旧程度和复用次数很敏感，尽可能每个数据只用一次

价值函数（Value）：需要更高的数据多样性，可以通过复用数据来提升性能

PPG: https://arxiv.org/pdf/2009.04416.pdf
PPG 详解补充材料：https://github.com/opendilab/PPOxFamily/blob/main/chapter3_obs/chapter3_supp_ppg.pdf

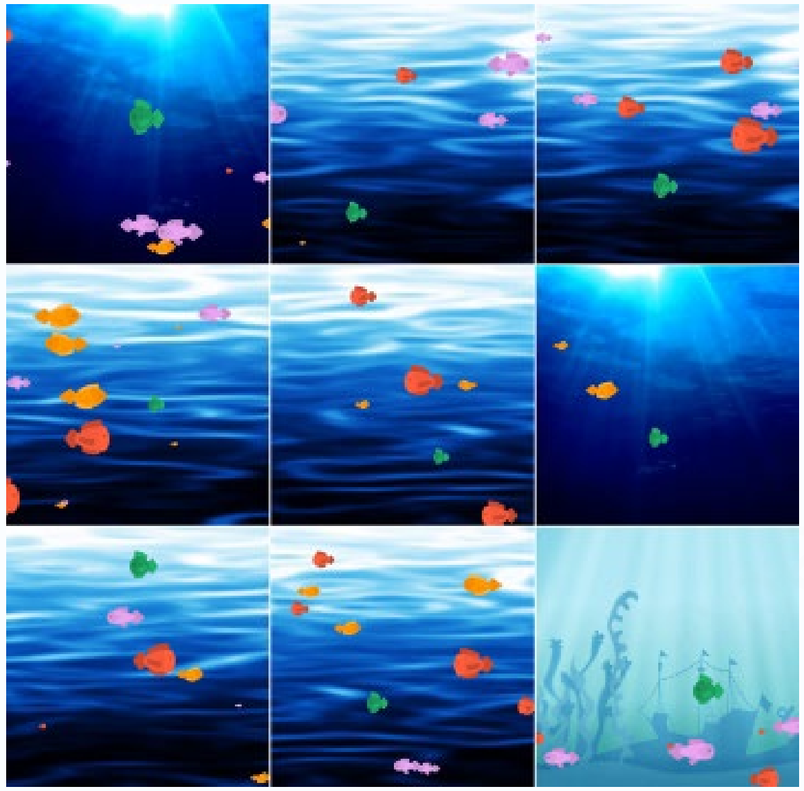
理论：Actor和Critic分离编码器训练

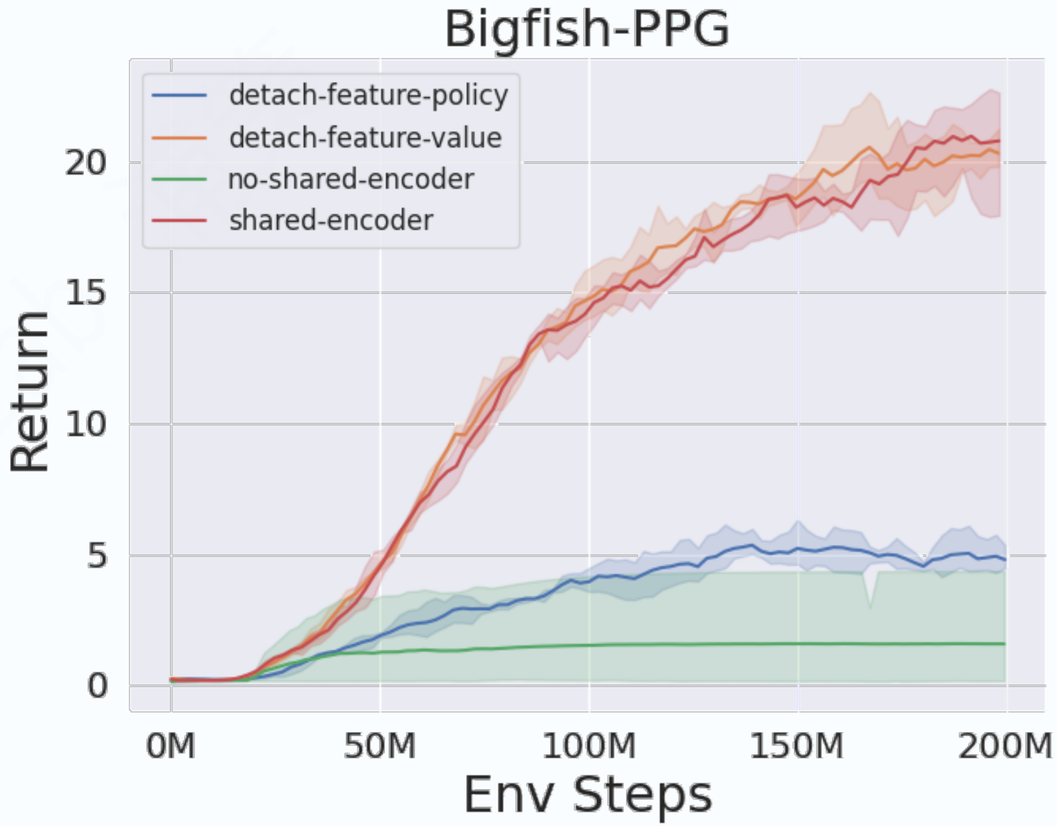


对于高维观察（比如图片）空间：

- Policy 和 Value 共享编码器是非常重要的
- 但 Policy 和 Value 对于编码器具体有什么样的影响关系，二者是缺一不可，还是各有不同的作用？

实践：PPO+大鱼吃小鱼(Procgen)





Procgen: https://openai.com/five/
DI-engine + Procgen Doc: https://di-engine-docs.readthedocs.io/zh_CN/latest/13_envs/procgen_zh.html
实验细节：https://github.com/opendilab/PPOxFamily/issues/8

代码：如何理解计算图中的梯度流动

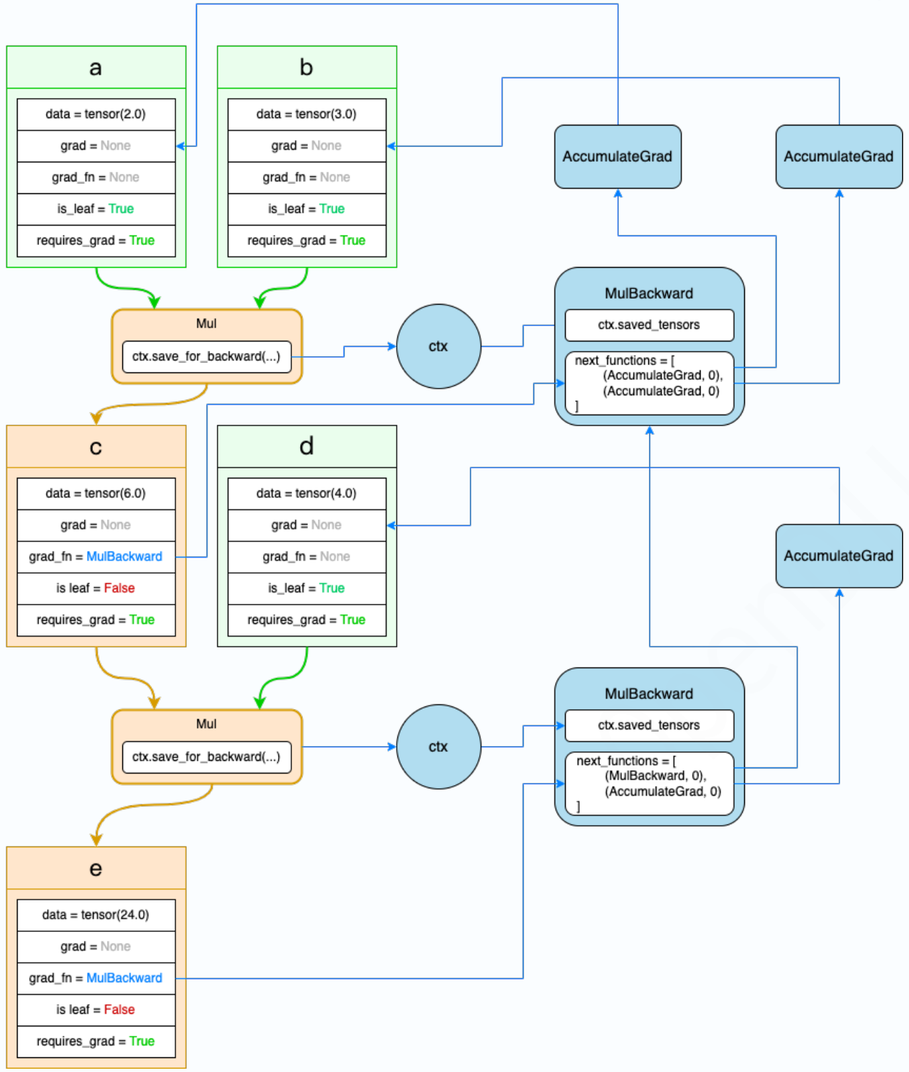
a =torch.tensor(2.0, requires_grad=True)

b= torch.tensor(3.0. requires_grad=True)

c=a* b

d= torch.tensor(4.0, requires_grad=True)

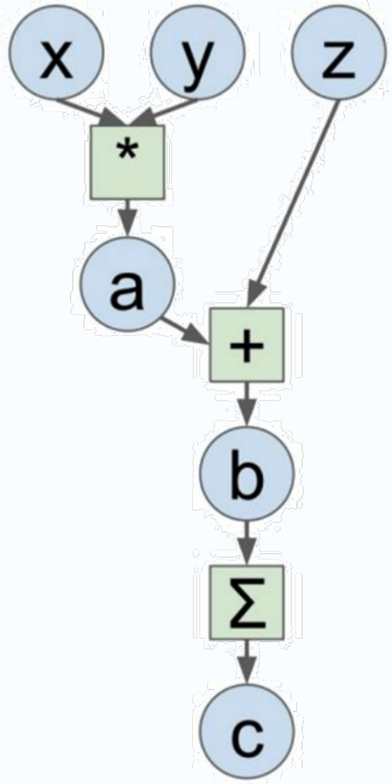
e=c* d




```python
import numpy as np
np.random.seed(0)


# generte data
B, D = 3, 4

x = np.random.randn(B, D)
y = np.random.randn(B, D)
z = np.random.randn(B, D)
# forward
a = x * y
b = a + z
c = np.sum(b)
# backward
grad_c = 1.0
grad_b = grad_c * np.ones((B, D))
grad_a = grad_b.copy()
grad_z = grad_b.copy()
grad_x = grad_a * y
grad_y = grad_a * x
```



Autograd: https://pytorch.org/tutorials/beginner/introyt/autogradyt_tutorial.html

完整代码示例：https://opendilab.github.io/PPOxFamily/

总结：PPO + 观察空间

小节	技术要点	代表决策任务
向量观察空间	• 统一量纲+特征编码设计 • 不变性与等变性概述	机器人控制 交通信号控制
图片观察空间	• 视觉信息预处理+运动信息建模 • 网络架构设计（LN）	视频游戏（超级马里奥） 棋类游戏（围棋）
复杂结构化观察空间	• 应用对应模态数据经典的网络架构 • 灵活利用 skip connection • 根据数据模态特性定制化设计	自动驾驶 三消类游戏（羊了个羊） 即时战略游戏（星际争霸2）
通用训练方法	• Actor和Critic是否共享编码器 • 表征学习 + 强化学习联合优化	/

下节预告

（四）探索之法：解密稀疏奖励空间

- 稀疏奖励空间的万能钥匙
- 多尺度奖励空间的锦囊妙计