CSC 36000:
Modern Distributed Computing *NextGen with AI Agents*

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Introduction to JAX for Distributed Computing

What is JAX?

JAX is a Python library for high-performance numerical computing and machine learning research.

- NumPy on Accelerators: JAX
- Composable Function Transformations: Apply transformations to your Python functions:
    - jit: Just-in-time compilation for speed.
    - grad: Automatic differentiation for optimization.
    - vmap: Automatic vectorization for batching.
    - pmap: Parallelization across multiple devices.

Example

```
import jax import jax.numpy as jnp
# A simple Python function
def predict(params, inputs):
    return jnp.dot(inputs, params)

# Let's transform it!
grad_fn = jax.grad(predict)
fast_grad_fn = jax.jit(grad_fn)
```

Just in time Compilation

```
from jax import jit

# A slow Python loop
def slow_function(x):
  for _ in range(5):
    x = x * 0.5 + 1.0
  return x

# A fast, compiled version
fast_function = jit(slow_function)

# The first run is slow (compilation), but subsequent runs are lightning fast!
```

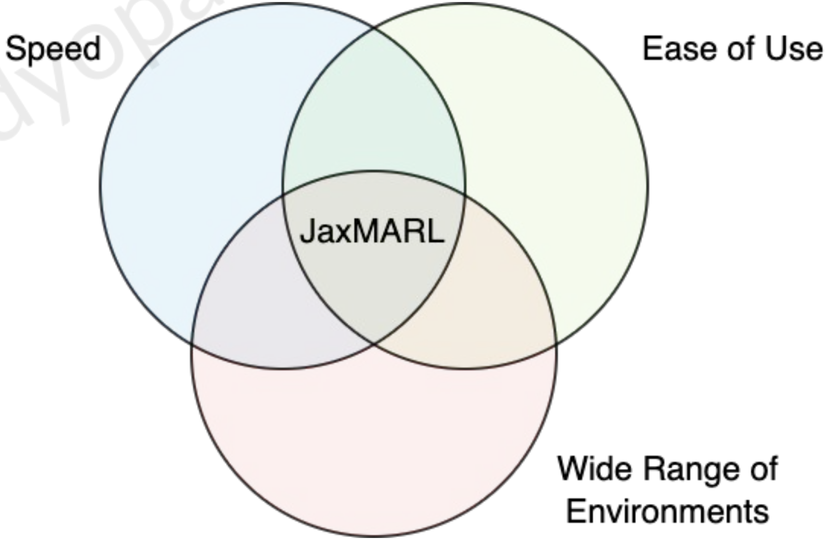
pmap

```
from jax import pmap

# Function to run on each device
def device_fn(x):
  # Each device gets a CHUNK of x
  return x * 2

# Create data and split it across devices
# Let's assume we have 8 devices
data = jnp.arange(8 * 3).reshape((8, 3)) # 8 rows, one for each device

# `pmap` compiles the function and runs one copy on each device
parallel_fn = pmap(device_fn)

# Run it! JAX handles sending each row to a different device.
result = parallel_fn(data)
print(result.shape) # Output: (8, 3)
```

Addressing Speedup with JAXMARL

Introduction

- Multi-Agent RL can be pretty slow!
- JAX-enabled hardware acceleration can make it 12500x faster!
- This means that experiments that once took days now take hours or minutes



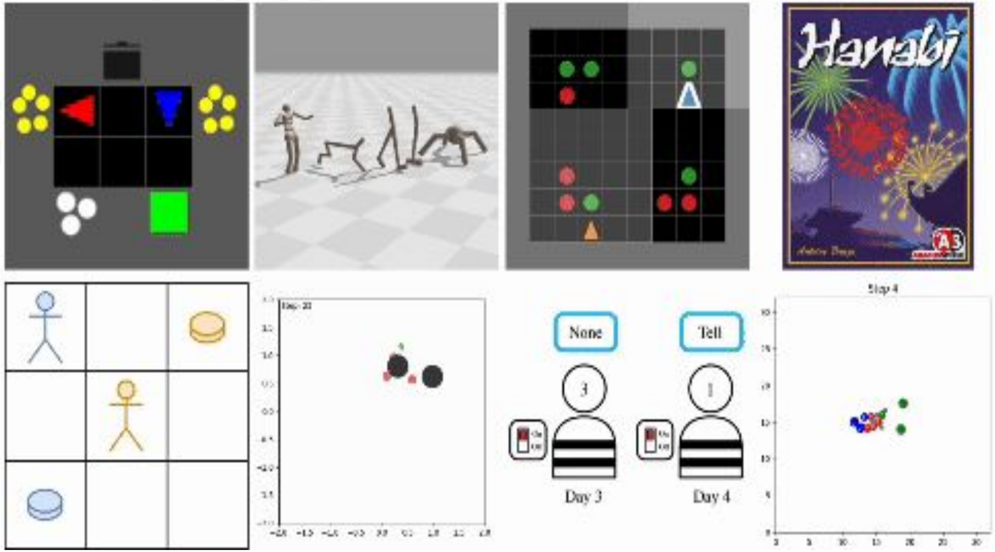
JAXMARL

- JAX is a Python library that makes writing hardware accelerated code easy
- JAXMARL co-locates the AI agent and Multi-Agent RL environment on a GPU
- JAXMARL vectorizes environment rollouts using a single function call

Multi-Agent Environments

- We implement 8 popular MARL environments
- We provide Q-learning and PPO baseline

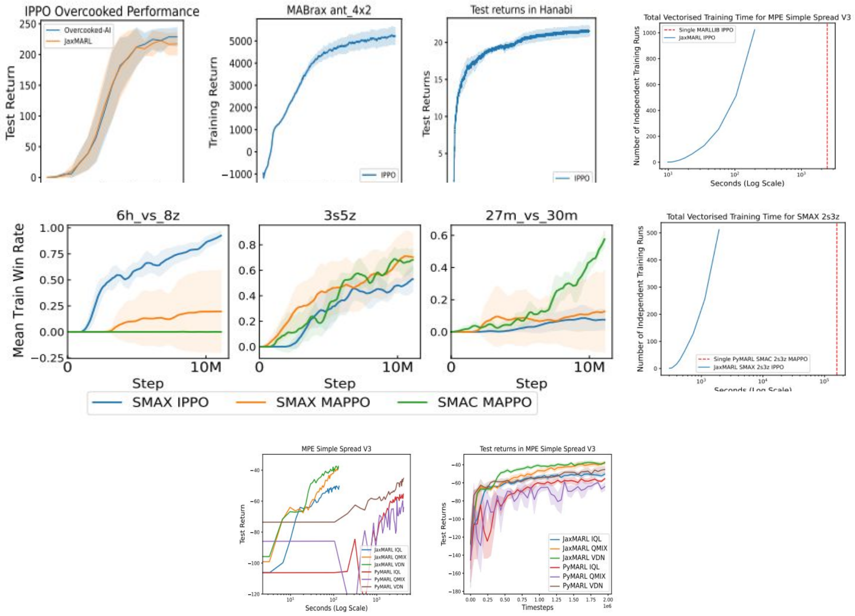
```python
import jax
from jaxmarl import make

key = jax.random.PRNGKey(0)
key, key_reset, key_act, key_step = jax.random.split(key, 4)

# Initialise and reset the environment.
env = make('MPE_simple_world_comm_v3')
obs, state = env.reset(key_reset)

# Sample random actions.
key_act = jax.random.split(key_act, env.num_agents)
actions = {agent: env.action_space(agent).sample(key_act[i]) \
           for i, agent in enumerate(env.agents)}

# Perform the step transition.
obs, state, reward, done, infos = env.step(key_step, state, actions)
```



Baseline and Speed Results

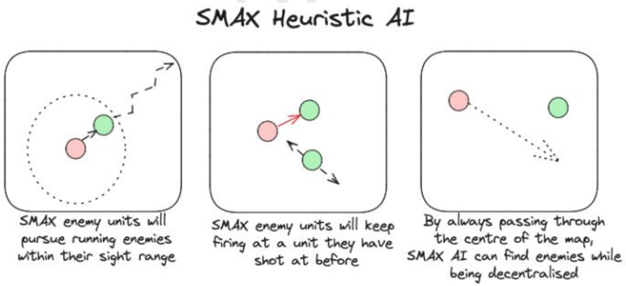
- The Jax Environments are much much faster than CPU baselines!
- Our evaluations demonstrate that our baselines are correct and can train quickly!

Environment	Original, 1 Env	Jax, 1 Env	Jax, 100 Envs	Jax, 10k Envs	Maximum Speedup
MPE Simple Spread	8.34×10^4	5.48×10^3	5.24×10^5	3.99×10^7	4.78×10^2
MPE Simple Reference	1.46×10^5	5.24×10^3	4.85×10^5	3.35×10^7	2.29×10^2
Switch Riddle	2.69×10^4	6.24×10^3	7.92×10^5	6.68×10^7	2.48×10^3
Hanabi	2.10×10^3	1.36×10^3	1.05×10^5	5.02×10^6	2.39×10^3
Overcooked	1.91×10^3	3.59×10^3	3.04×10^5	1.69×10^7	8.85×10^3
MABrax Ant 4x2	1.77×10^3	2.70×10^2	1.81×10^4	7.62×10^5	4.31×10^2
Starcraft 2s3z	8.31×10^1	5.37×10^2	4.53×10^4	2.71×10^6	3.26×10^4
Starcraft 27m vs 30m	2.73×10^1	1.45×10^2	1.12×10^4	1.90×10^5	6.96×10^3
STORM	–	2.48×10^3	1.75×10^5	1.46×10^7	–
Coin Game	1.97×10^4	4.67×10^3	4.06×10^5	4.03×10^7	2.05×10^3



Star-Craft with SMAX

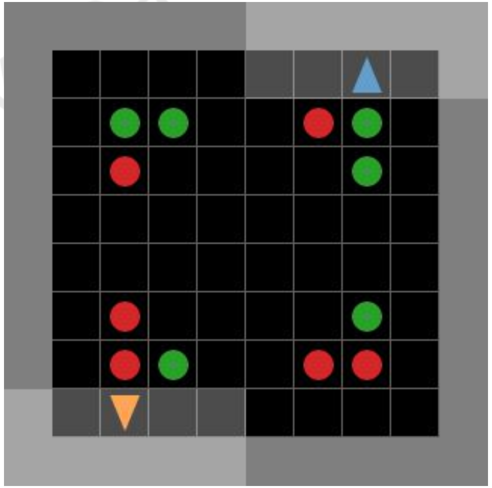
- We improve on SMAC and SMACv2's heuristics in SMAX
- The enemy heuristic is now fully decentralised meaning win-rates below 50% represent a concrete failure to learn
- SMAX is also faster and in pure Python so more customisable!



Scenario	Ally Units	Enemy Units	Start Positions
2s3z	2 stalkers and 3 zealots	2 stalkers and 3 zealots	Fixed
3s5z	3 stalkers and 5 zealots	3 stalkers and 5 zealots	Fixed
5m_vs_6m	5 marines	6 marines	Fixed
10m_vs_11m	10 marines	11 marines	Fixed
27m_vs_30m	27 marines	30 marines	Fixed
3s5z_vs_3s6z	3 stalkers and 5 zealots	3 stalkers and 6 zealots	Fixed
3s_vs_5z	3 stalkers	5 zealots	Fixed
6h_vs_8z	6 hydralisks	8 zealots	Fixed
smacv2_5_units	5 uniformly randomly chosen	5 uniformly randomly chosen	SMACv2-style
smacv2_10_units	10 uniformly randomly chosen	10 uniformly randomly chosen	SMACv2-style
smacv2_20_units	20 uniformly randomly chosen	20 uniformly randomly chosen	SMACv2-style

STORM

- STORM: Spatial-Temporal Representations of Matrix Games
- STORM allows to represent matrix games as grid-world scenarios
- Presents new challenges such as partial observability, multi-step agent interactions and longer time horizons



Questions?