IXO Modelling

Terminology:

- c_ - IXO-Cosmos equivalent of Ethereum tokens
- native - native to IXO-Cosmos network
- cIXOS - staking tokens
- cIXO - utility tokens

Actor flow:

1. Participant buys into market maker with Dai, and is given Ethereum based IXO tokens.
2. Participant stakes IXO into the brokerage mechanism in exchange for IXOS. The IXO stake is backed by a proportion of the DAI collateral pool.
3. The IXO and IXOS pools are mirrored on the IXO-Cosmos network, and backed by DAI - post IBC these assets can be made native to the IXO-Cosmos network.
4. cIXO become utility tokens that can be spent in IXO-Cosmos network, and minted through block rewards to be rewarded to actors in the system. The utility comes from the asset backing of the cIXO tokens in the brokerage.

Working example:

1. Participant purchases 100 IXO tokens @ 0.1 DAI per IXO for a total of 10 DAI.
2. Participant provides liquidity in brokerage contract by depositing 50 IXO, retaining 50 IXO for the time being. The asset backing is provided by the bonding curve Dai collateral pool.
3. Participant is rewarded with 50 IXOS tokens to represent the proportion of the liquidity provided.
4. These IXOS tokens are mirrored and can be used within the IXO-Cosmos network as equivalent cIXOS tokens, these are low velocity and are essentially staked for IXO-Cosmos incentive rewards.
5. Participants within the IXO-Cosmos network, who are incentivized/rewarded with cIXO tokens for supporting the network roles, may atomic swap/mirror their cIXO tokens for IXO tokens and in effect DAI via the bonding curve.

Observations:

- Based on last two actions - what is the best way to couple the cIXO token value to the DAI reserve to maintain the cross blockchain peg?
- Objective - make the cIXO utility token stable.
- cIXOS staked on IXO-Cosmos side for various incentive rewards.

Dependancies

```
import sys
sys.path.append("../../venv/lib/python3.7/site-packages" )

import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import seaborn as sns
import networkx as nx
from scipy.stats import expon
import math
import pickle

from cadCAD.configuration.utils import config_sim #env_trigger, var_substep_trigger, config_sim, psub_list
from cadCAD.engine import ExecutionMode, ExecutionContext, Executor
from cadCAD.configuration import append_configs

%matplotlib inline
```

```
from helpers import *
from bonding_curve_eq import *
```

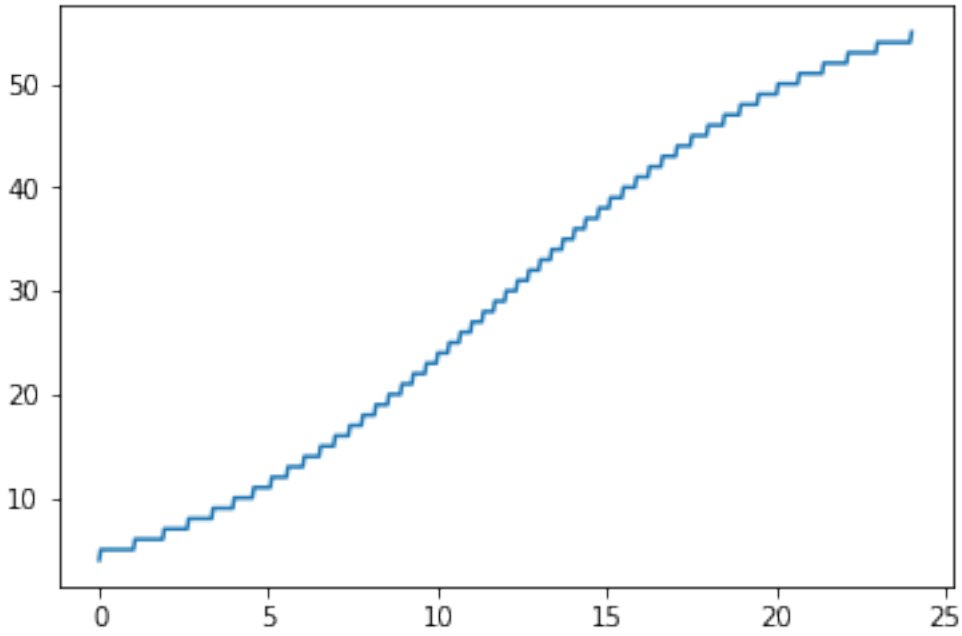
Liquidity Mechanisms and Actors Overview

```
from enum import Enum, auto
class Nodes(Enum):
    POOL = auto() # Pool of specific token / collateral
    # Mechanisms
    MARKET_MAKER = auto() # Issues IXO tokens in exchange for DAI
    BROKERAGE = auto() # Issues IXOS / staking tokens to delegators
    # Actors
    SERVICE_PROVIDER = auto() # makes claims about contributions and state of project
    EVALUATOR = auto() # validates claims
    DELEGATOR = auto() # stakes into the brokerage to provide liquidity
    PARTICIPANT = auto() # generic type for any user of IXO-Cosmos utility tokens

class Edges(Enum):
    BALANCE = auto()
    BRIDGE = auto() # IBC style mirror

# IBC Ethereum Peg-Zone:
# 1. IXO from AMM and DAI staked into reserve pool by delegators in exchange for IXOS
# 2. cIXO and cIXOS matched on IXO-Cosmos network
# 3. This mechanism can be spun down, while maintaining the liquidity created, when the IBC mechanism is o
```

Global Parameters

```
liquidity_provider_fee = .03 # percent
tax = 0 # exit tax - introduces friction and possibly funds to prime stability mechanisms
theta = 0 #.35 # Funding pool taxation - 0 implies all contributions allocated to market

# From scenario spreadsheet
initial_ixo_supply = 2e9
initial_ixo_price = .02
initial_ixo_reserve = initial_ixo_supply * initial_ixo_price

founders_stake = .1 # percent
initial_ixos_supply = initial_ixo_supply * founders_stake # initial supply of staking vouchers

initial_ixo_price = .10 # average IXO price from ixo.world Euro cents
initial_ixos_price = .20 # staking voucher price from AMM in Euro cents

ixo_delegation_distribution_reserve = 1e6
ixo_delegation_distribution_supply = 1e6/initial_ixo_price #200e6 # 5 strategic delegations worth Euro 1 M

# Augmented bonding curve parameters
# Hatch state
d0 = initial_ixo_reserve/1e6 # million DAI
p0 = initial_ixo_price # DAI per tokens

R0 =  d0*(1-theta) # million DAI
S0 = d0/p0

kappa = 1 # Bonding curve curvature - using an initial kappa value of 1 we can keep a constant token price

# Brokerage - Kyber Fed Price Reserve
```

```
# Policy to bound proposed conversion rate
sanity_rate = 10 # 1 DAI = 10 IXO
reasonable_difference = .1 # percent

# Target portfolio
# 50% DAI / 50% IXO

# Rebalancing
# Or: auto_instant - rebalance performed after every trade
time_spacing = 1 # time period after which to perform another rebalance
price_spacing_diff = .5 # percentage difference from last rebalance after which to perform another rebalan

# Pricing
maximum_spread = 0.02 # dictated by for example Kyber
minimum_spread = 0.005
spread = 0.01 # dependant on liquidity
quoted_price = 0 # TODO

# cadCAD configuration
time_steps = 24 # months, use days for more granularity

amm_initial_reserve, amm_initial_invariant, amm_initial_spot_price = initialize_bonding_curve(initial_ixo_

# Number of actors
max_delegators = 20
max_validators = 20
max_service_providers = 20
max_participants = max_delegators + max_validators + max_service_providers

# Sigmoidal growth
default_inflection = time_steps/2
default_slope = 1/5

def sigmoidal_growth(step, max_value, inflection=default_inflection, slope=default_slope):
    y = np.divide(max_value, (1 + np.power(np.e, -np.multiply(np.subtract(step, inflection), slope))))
    y = np.floor(y)
    y[y < 0] = 0
    return y

x = np.linspace(0, time_steps, 500)
y = sigmoidal_growth(x, max_participants)

plt.plot(x, y)
plt.show()
```



cadCAD Parameters and Initial State

```
# cadCAD Parameter Sets
#########################################################################

# amm == automated market maker
# brk == brokerage

# params = {
#     'brokerage': {
#         'sanity_rate': 10,
#         'max_spread': .02,
#     }
# }

params = {
    'sweep': [1], # for selecting parameter sweep from results
    # Automated Market Maker parameters
    'amm.kappa': [kappa],
    'amm.invariant': [amm_initial_invariant],
    'amm.tax_rate': [0],
    # Brokerage
    'brk.sanity_rate': [10], # 1 DAI = 10 IXO
    'brk.reasonable_diff': [.5], # percent
    'brk.rebalance_diff': [False], # percentage difference from last rebalance after which to perform anot
    'brk.max_spread': [.02], # price
    'brk.min_spread': [.005],
    'max_delegators': [20],
    'max_validators': [20],
    'max_service_providers': [20],
    'max_participants': [60], # Sum of above
}

initial_state = {
    'amm.supply': initial_ixo_supply,
```

```
    'amm.reserve': amm_initial_reserve,
    'amm.spot_price': amm_initial_spot_price,
#     'timestamp': '2019-01-01 00:00:00'
}
```

Brokerage / liquidity framework

```
# Brokerage framework / liquidity provision (see Uniswap/Kyber)
# https://github.com/runtimeverification/verified-smart-contracts/blob/uniswap/uniswap/x-y-k.pdf
# Newly added... found post setting this up: https://github.com/BlockScience/uniswap

# e.g. reserve == DAI
# e.g. supply == IXO
# e.g. voucher == IXOS

def add_liquidity(network, reserve, supply, voucher, tokens, value):
    reserve_balance = get_pool_balance(network, reserve)
    supply_balance = get_pool_balance(network, supply)
    voucher_balance = get_pool_balance(network, voucher)

    alpha = value/reserve_balance

    dr = alpha*reserve_balance
    ds = alpha*supply_balance
    dv = alpha*voucher_balance

    #new_reserve = (1 + alpha)*reserve_balance
    #new_supply = (1 + alpha)*supply_balance
    #new_vouchers = (1 + alpha)*voucher_balance

    return (dr, ds, dv)

def remove_liquidity(liquidity_tokens, reserve_balance, supply_balance):
    reserve_balance = 0 # e.g. DAI
    supply_balance = 0 # e.g. IXO
    liquidity_token_balance = 0 # e.g. IXOS

    alpha = liquidity_tokens/liquidity_token_balance

    new_reserve = (1 - alpha)*reserve_balance
    new_supply = (1 - alpha)*supply_balance
    new_liquidity_tokens = (1 - alpha)*liquidity_token_balance

    return False

def get_input_price(dx, reserve_balance, supply_balance):
    x_balance = 0
    y_balance = 0
    rho = 0 # trade fee

    alpha = dx/x_balance
    gamma = 1 - rho

    dy = (alpha*gamma / (1 + alpha*gamma))*y_balance

    new_x = (1 + alpha)*x_balance
    new_y = y_balance - dy
```

```
    return False

def get_output_price(dy, reserve_balance, supply_balance):
    x_balance = 0
    y_balance = 0
    rho = 0 # trade fee

    beta = dy/y_balance
    gamma = 1 - rho

    dx = (beta / (1 - beta))*(1 / gamma)*x_balance

    new_x = x_balance + dx
    new_y = (1 - beta)*dy

    return False

# Token trading
def collateral_to_token(value, reserve_balance, supply_balance):
    dv = get_input_price(value, reserve_balance, supply_balance)

    new_reserve = reserve_balance + value
    new_supply = supply_balance - dv

    return False

def token_to_collateral(tokens, reserve_balance, supply_balance):
    dv = get_input_price(tokens, supply_balance, reserve_balance)

    new_reserve = reserve_balance - dv
    new_supply = supply_balance + value

    return False

def token_to_token():
    # Irrelevant for now
    return False
```

Initialize System

```
# Node generators
def add_new_pool(
        network,
        ticker):

    network.add_node(ticker, _type=Nodes.POOL.name)
    return network

def add_new_brokerage(
        network,
        _params=params,
        pair=('DAI', 'IXO')):

    pair_id = generate_pair_id(Nodes.BROKERAGE, pair)
    network.add_node(pair_id, _type=Nodes.BROKERAGE.name)
    network.add_edge(pair_id, pair[0], _type=Edges.BALANCE.name, balance=0)
```

```
    network.add_edge(pair_id, pair[1], _type=Edges.BALANCE.name, balance=0)
    network.add_edge(pair_id, pair[1], _type=Edges.BALANCE.name, balance=0)

    brokerage = {}
    brokerage['target'] = .5 # Target portfolio pair[0]:pair[1]
    brokerage['rate'] = _params['brk.sanity_rate'][0] #TODO
    brokerage['sanity_rate'] = _params['brk.sanity_rate'][0]
    brokerage['reasonable_diff'] = _params['brk.reasonable_diff'][0]
    brokerage['rebalance_diff'] = _params['brk.rebalance_diff'][0]
    brokerage['max_spread'] = _params['brk.max_spread'][0]
    brokerage['min_spread'] = _params['brk.min_spread'][0]
    brokerage['reserve_type'] = pair[0]
    brokerage['supply_type'] = pair[1]
    brokerage['voucher_type'] = pair[1] + 'S' # can be made more robust

    network.nodes[pair_id].update(brokerage)
    return network

def add_new_market_maker(
        network,
        _params=params,
        _initial_state=initial_state,
        pair=('DAI', 'IXO')): # Collateral -> distributed token

    pair_id = generate_pair_id(Nodes.MARKET_MAKER, pair)
    network.add_node(pair_id, _type=Nodes.MARKET_MAKER.name)

    network.add_edge(pair_id, pair[0], _type=Edges.BALANCE.name, balance=0)
    network.add_edge(pair_id, pair[1], _type=Edges.BALANCE.name, balance=0)

    market_maker = {}
    market_maker['pair'] = pair # Reserve/collateral -> supply/token
    market_maker['reserve_type'] = pair[0]
    market_maker['supply_type'] = pair[1]
    market_maker['kappa'] = _params['amm.kappa'][0]
    market_maker['invariant'] = _params['amm.invariant'][0]
    market_maker['tax_rate'] = _params['amm.tax_rate'][0]
    market_maker['spot_price'] = _initial_state['amm.spot_price']

    # Initialize pools
    reserve_edge = network.edges[(pair_id, pair[0])]
    supply_edge = network.edges[(pair_id, pair[1])]
    reserve_edge['balance'] = _initial_state['amm.reserve']
    supply_edge['balance'] = _initial_state['amm.supply']

    network.nodes[pair_id].update(market_maker)
    return network

def add_new_bridge(
        network,
        _params=params,
        pair=('IXO', 'cIXO')):

    network.add_edge(pair[0], pair[1], _type=Edges.BRIDGE.name)

def gen_new_participant(
```

```
        network,
        _params=params):

    participant = {}
    participant['key'] = 'value'

    return participant

def initialize_network():
    network = nx.Graph()
    color_map = []

    pools = ['IXOS','cIXOS']

    for ticker in pools:
        color_map.append('orange')
        add_new_pool(network, ticker)

    brokerage_pairs = [
        ('DAI','IXO'),
        ('cDAI','cIXO')
    ]

    for pair in brokerage_pairs:
        for ticker in pair:
            color_map.append('green')
            add_new_pool(network, ticker)
        color_map.append('pink')
        add_new_brokerage(network, params, pair)

    market_maker_pairs = [('DAI','IXO')]

    for pair in market_maker_pairs:
        for ticker in pair:
            color_map.append('blue')
            add_new_pool(network, ticker)
        color_map.append('pink')
        add_new_market_maker(network, params, initial_state, pair)

    bridges = [
        ('DAI', 'cDAI'),
        ('IXO', 'cIXO'),
        ('IXOS', 'cIXOS'),
    ]

    for pair in bridges:
        add_new_bridge(network, params, pair)

    return (network, color_map)

# Policies
def driving_process(_params, step, sL, s):
    network = s['network']

    participants = get_node_ids_of_type(network, Nodes.PARTICIPANT.name)
    participant_growth = sigmoidal_growth([s['timestep']], _params['max_participants'])[0]
```

```
    new_participants = math.ceil(participant_growth - len(participants))

    if new_participants:
        zipOf = zip(range(new_participants), expon.rvs(size=new_participants, loc=0.0, scale=1000))
        new_participants_collateral = dict(zipOf)
    else:
        new_participants_collateral = {}

    return({'new_participants': new_participants,
            'new_participants_collateral': new_participants_collateral})

def bond_process(_params, step, sL, s):
    network = s['network']

    participants = get_node_ids_of_type(network, Nodes.PARTICIPANT.name)
    participants_with_collateral = filter(lambda p: network.edges[(p, 'DAI')].get('balance', 0)>0, partici

    transactions = []
    for p in participants_with_collateral:
        transactions.append({
            'from': p,
            'type': 'DAI',
            'handler': ('DAI', 'IXO'),
            # Transfer all DAI collateral holdings to DAI:IXO market maker
            'value': network.edges[(p, 'DAI')]['balance'],
        })

    return({'transactions': transactions})

def provide_liquidity(_params, step, sL, s):
    network = s['network']

    participants = get_node_ids_of_type(network, Nodes.PARTICIPANT.name)
    brokers = get_node_ids_of_type(network, Nodes.BROKERAGE.name)
    participants_with_collateral = filter(lambda p: network.edges[(p, 'IXO')].get('balance', 0)>0, partici

    transactions = []
    for p in participants_with_collateral:
        transactions.append({
            'from': p,
            'type': generate_pair_id(Nodes.BROKERAGE, ('DAI', 'IXO')),
            'handler': ('DAI', 'IXO'),
            # Transfer all IXO, DAI backed collateral, holdings to brokerage
            'value': network.edges[(p, 'IXO')]['balance'],
        })

    return({'transactions': transactions})

def participants_decisions(params, step, sL, s):
    network = s['network']

    print('TODO')
    return({})

# Mechanisms for updating the state based on driving processes
def update_network(_params, step, sL, s, _input):
```

```
    network = s['network']

    new_participants = _input['new_participants'] # Number of
    new_participants_collateral = _input['new_participants_collateral'] # Dict

    for i in range(new_participants):
        index = len([node for node in network.nodes])
        network.add_node(index, _type=Nodes.PARTICIPANT.name)
        participant = gen_new_participant(network)
        network.node[index].update(participant)
        # Deposit seed collateral
        network.add_edge(index, 'DAI', balance=new_participants_collateral[i])

    key = 'network'
    value = network

    return (key, value)

def get_pool_balance(network, pool_node):
    edges = network.edges(pool_node)
    with_balance = filter(lambda edge: network.edges[edge].get('balance', 0) > 0, edges)
    balance = sum([network.edges[edge]['balance'] for edge in with_balance])
    assert(balance >= 0)
    return balance

def update_balances(_params, step, sL, s, _input):
    network = s['network']

    # Process transactions and update balances
    # [{'from': 10, 'type': 'DAI', 'handler': ('DAI', 'IXO'), 'value': 0}]
    transactions = _input['transactions']

    for tx in transactions:
        handler_id = generate_pair_id(Nodes.MARKET_MAKER, tx['handler'])
        handler = network.nodes[handler_id]
        assert(handler['_type'] == Nodes.MARKET_MAKER.name)

        # Collateral -> token; e.g. DAI -> IXO
        participant = tx['from']
        reserve_pool = handler['reserve_type']
        supply_pool = handler['supply_type']
        reserve = get_pool_balance(network, handler['reserve_type'])
        supply = get_pool_balance(network, handler['supply_type'])

        if tx['type'] == reserve_pool: # Mint
            #print('Mint %s' % tx['value'])
            V0 = invariant(
                reserve,
                supply,
                handler['kappa'])
            deltaS, realized_price = mint(
                tx['value'],
                reserve,
                supply,
                V0,
                handler['kappa'])
```

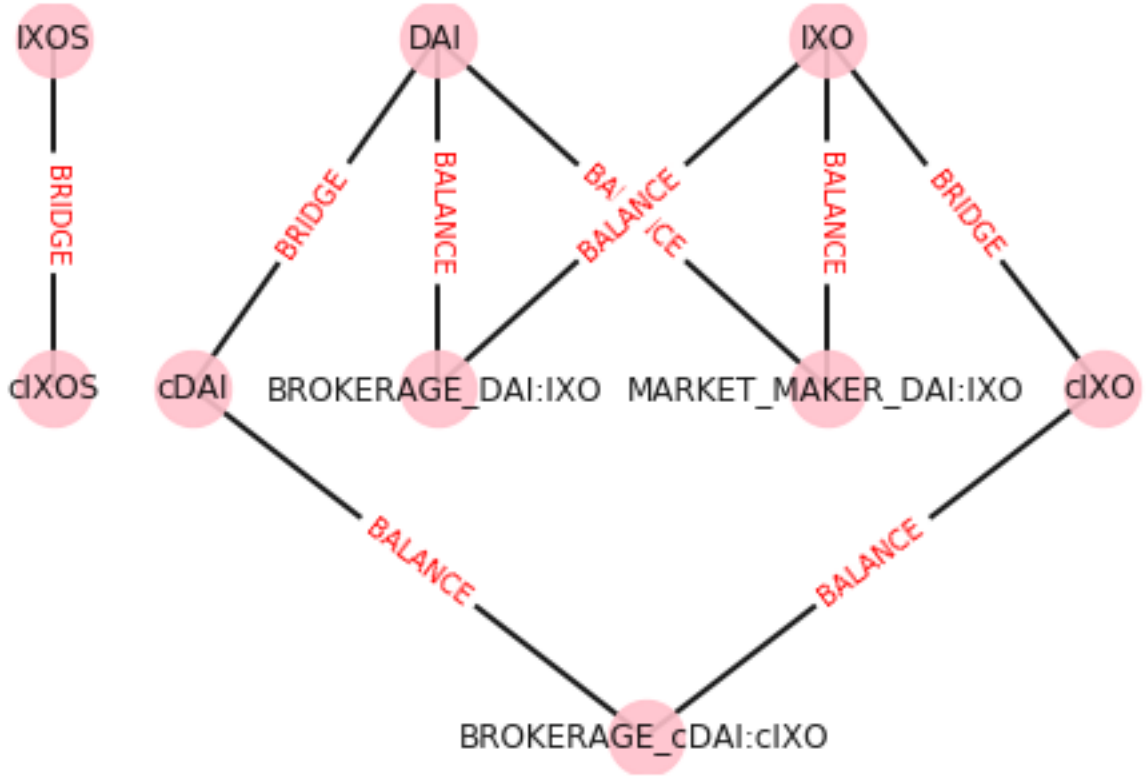
```
            # Update holdings
            network.edges[(participant, reserve_pool)]['balance'] -= tx['value'] # DAI decrease
            if not network.has_edge(participant, supply_pool):
                network.add_edge(participant, supply_pool, _type=Edges.BALANCE.name, balance=0)
            network.edges[(participant, supply_pool)]['balance'] += deltaS
            network.edges[(handler_id, reserve_pool)]['balance'] += tx['value']

            # Update market maker
            handler['invariant'] = V0
            handler['spot_price'] = spot_price(
                reserve,
                handler['invariant'],
                handler['kappa'])

        elif tx['type'] == supply_pool: # Withdraw
            #print('Withdraw %s' % tx['value'])
            V0 = invariant(
                reserve,
                supply,
                handler['kappa'])
            deltaR, realized_price = withdraw(
                tx['value'],
                reserve,
                supply,
                V0,
                handler['kappa'])

            # Update holdings
            print(participant)
            network.edges[(participant, reserve_pool)]['balance'] += deltaR # DAI increase
            network.edges[(participant, supply_pool)]['balance'] -= tx['value']
            network.edges[(handler_id, reserve_pool)]['balance'] -= deltaR

            # Update market maker
            handler['invariant'] = V0
            handler['spot_price'] = spot_price(
                reserve,
                handler['invariant'],
                handler['kappa'])

        else: raise # We shouldn't get here

    key = 'network'
    value = network

    return (key, value)

def update_brokerage(_params, step, sL, s, _input):
    network = s['network']

    # Process transactions and update balances
    # [{'from': 10, 'type': 'DAI', 'handler': ('DAI', 'IXO'), 'value': 0}]
    transactions = _input['transactions']

    for tx in transactions:
```

```
    handler_id = generate_pair_id(Nodes.BROKERAGE, tx['handler'])
    handler = network.nodes[handler_id]
    assert(handler['_type'] == Nodes.BROKERAGE.name)

    # Collateral -> token; e.g. DAI -> IXO
    participant = tx['from']
    reserve_pool = handler['reserve_type']
    supply_pool = handler['supply_type']
    voucher_pool = handler['voucher_type']
    reserve = get_pool_balance(network, handler['reserve_type'])
    supply = get_pool_balance(network, handler['supply_type'])

    if tx['type'] == handler_id: # Provide liquidity, get IXOS
        #print('Provide liquidity %s' % tx['value'])

        # Calculate a reasonable value for the supplied tokens
        market_maker = network.nodes[generate_pair_id(Nodes.MARKET_MAKER, tx['handler'])]
        V0 = invariant(
            reserve,
            supply,
            market_maker['kappa'])
        deltaR, realized_price = withdraw(
            tx['value'],
            reserve,
            supply,
            market_maker['invariant'],
            market_maker['kappa'])

        dr, ds, dv = add_liquidity(
            network,
            reserve_pool,
            supply_pool,
            voucher_pool,
            tx['value'],
            deltaR)
        #print((dr, ds, dv))

        # Broker balance increases, provider balance decreases, net pool balance remains
        network.edges[(handler_id, reserve_pool)]['balance'] += dr
        network.edges[(handler_id, supply_pool)]['balance'] += ds

        network.edges[(participant, reserve_pool)]['balance'] -= dr
        network.edges[(participant, supply_pool)]['balance'] -= ds
        if not network.has_edge(participant, voucher_pool):
            network.add_edge(participant, voucher_pool, _type=Edges.BALANCE.name, balance=0)
        network.edges[(participant, voucher_pool)]['balance'] += dv

    elif tx['type'] == reserve_pool: # Swap reserve (DAI) for tokens (IXO)
        print('TODO')
    elif tx['type'] == supply_pool: # Swap tokens for reserve
        print('TODO')
    else: raise # We shouldn't get here

key = 'network'
value = network
```

```
    return (key, value)
```

Initialize Network

```
network, color_map = initialize_network()
pos = nx.drawing.nx_agraph.graphviz_layout(network, prog='dot') #spring_layout(network, k=0.15,iterations=

plt.figure()
nx.draw(
    network, pos, edge_color='black', width=2, linewidths=1,
    node_size=800, node_color='pink', alpha=0.9,
    labels={node: node for node in network.nodes()})

nx.draw_networkx_edge_labels(
    network, pos,
    edge_labels={(u,v): d['_type'] for u,v,d in network.edges(data=True)},
    font_color='red')

plt.axis('off')
plt.show()

#nx.draw_kamada_kawai(network, node_color=color_map, font_weight='bold', with_labels=True)

initial_state.update({
    'network': network,
})
```



Configure cadCAD

```
runs = 1 # Monte Carlo runs

# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
# Settings of general simulation parameters, unrelated to the system itself
# `T` is a range with the number of discrete units of time the simulation will run for;
# `N` is the number of times the simulation will be run (Monte Carlo runs)
# In this example, we'll run the simulation once (N=1) and its duration will be of 10 timesteps

simulation_parameters = config_sim({
    'T': range(time_steps),
    'N': runs,
    'M': params
})
simulation_parameters
```

```
[{'N': 1,
  'T': range(0, 24),
  'M': {'sweep': 1,
   'amm.kappa': 1,
   'amm.invariant': 10.0,
   'amm.tax_rate': 0,
   'brk.sanity_rate': 10,
   'brk.reasonable_diff': 0.5,
   'brk.rebalance_diff': False,
   'brk.max_spread': 0.02,
   'brk.min_spread': 0.005,
   'max_delegators': 20,
   'max_validators': 20,
   'max_service_providers': 20,
   'max_participants': 60}}]
```

Perform Simulation

```
# ts_format = '%Y-%m-%d %H:%M:%S'
# t_delta = timedelta(days=30, minutes=0, seconds=0)
# def time_model(_g, step, sL, s, _input):
#     y = 'time'
#     x = ep_time_step(s, dt_str=s['time'], fromat_str=ts_format, _timedelta=t_delta)
#     return (y, x)

# exogenous_states = {
# #     'time': time_model
# }
# env_processes = {}

partial_state_update_blocks = [
    { # Generate new participants
        'policies': {
            'generate': driving_process,
        },
        'variables': {
            'network': update_network,
        }
    },
    {
        'policies': {
```

```
            'bond': bond_process,
        },
        'variables': {
            'network': update_balances,
        }
    },
    { # Participants provide liquidity via brokerage
        'policies': {
            'provide': provide_liquidity,
        },
        'variables': {
            'network': update_brokerage,
        }
    },
#     { # Brokerage rebalance
#         'policies': {
#             'rebalance': brokerage_rebalance,
#         },
#         'variables': {
#             'network': update_brokerage,
#         }
#     },
    #TODO: sync bridges
#     { # Accounting
#         'policies': {
#             'participants_act': participants_decisions,
#         },
#         'variables': {
#             'network': update_holdings,
#             'amm.supply': update_supply,
#             'amm.reserve': update_reserve,
#             'amm.spot_price': update_price,
#         }
#     }
]

append_configs(
    initial_state=initial_state, #dict containing variable names and initial values
    partial_state_update_blocks=partial_state_update_blocks, #dict containing state update functions
    sim_configs=simulation_parameters, #dict containing simulation parameters
#     raw_exogenous_states=exogenous_states,
#     env_processes=env_processes
)

sys.setrecursionlimit(10000)
from cadCAD import configs

exec_mode = ExecutionMode()
exec_context = ExecutionContext(context=exec_mode.multi_proc)
run = Executor(exec_context=exec_context, configs=configs)

i = 0
verbose = False
results = {}
for raw_result, tensor_field in run.execute():
    result = pd.DataFrame(raw_result)
    if verbose:
```

```
        print()
        print(f"Tensor Field: {type(tensor_field)}")
        print(tabulate(tensor_field, headers='keys', tablefmt='psql'))
        print(f"Output: {type(result)}")
        print(tabulate(result, headers='keys', tablefmt='psql'))
        print()
    results[i] = {}
    results[i]['result'] = result
    results[i]['simulation_parameters'] = simulation_parameters[i]
    i += 1
```

```
[{'N': 1, 'T': range(0, 24), 'M': {'sweep': 1, 'amm.kappa': 1, 'amm.invariant': 10.0, 'amm.tax_rate': 0, '
```

```
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by BlockScience

Execution Mode: multi_proc: [<cadCAD.configuration.Configuration object at 0x7f0304c03198>]
Configurations: [<cadCAD.configuration.Configuration object at 0x7f0304c03198>]
```
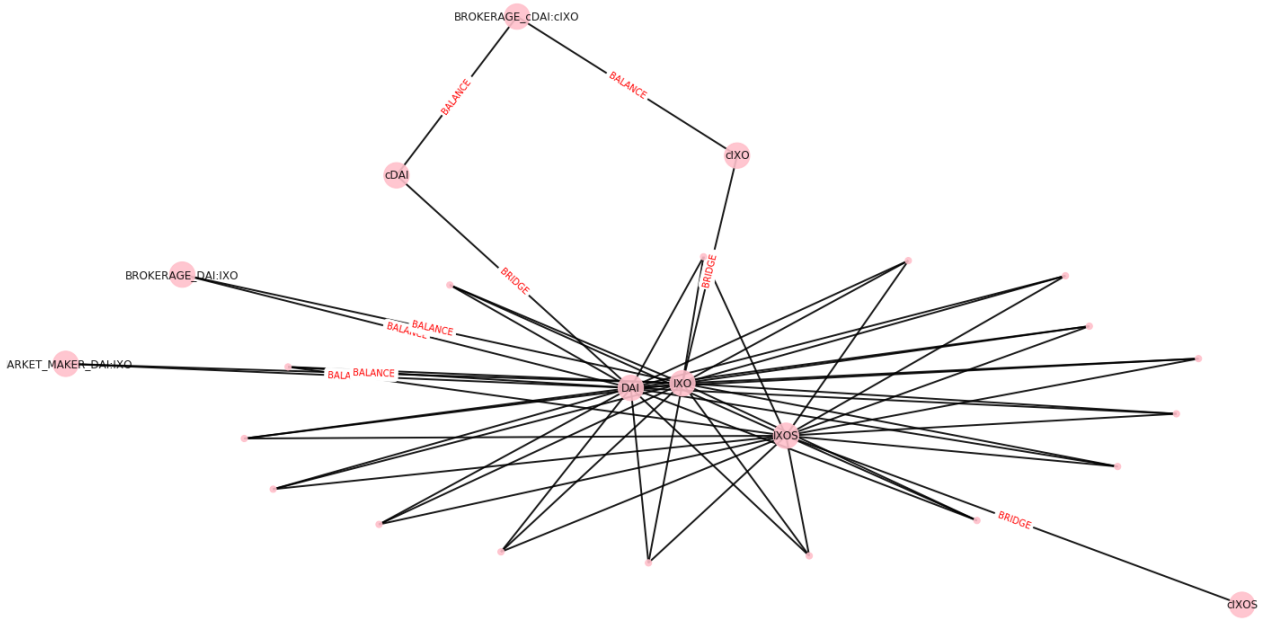

Model Data Analysis

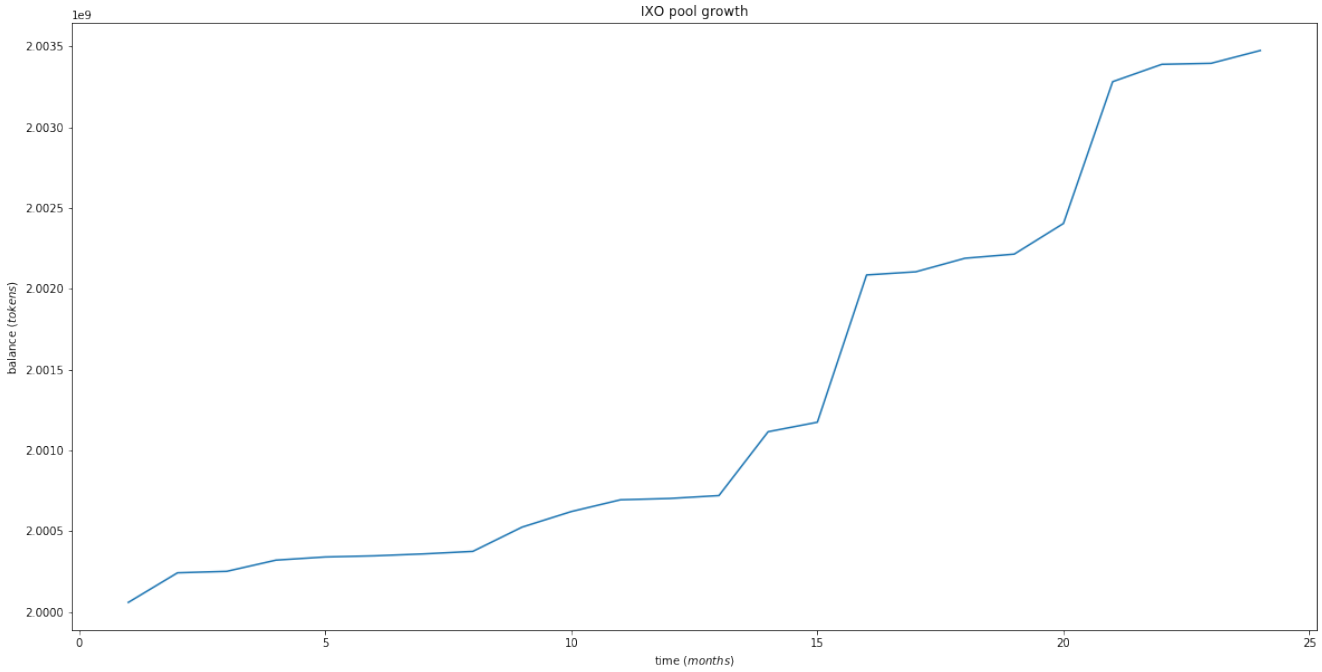
```
# Choose which experiment parameter configuration to use, integer starting from zero
import os

def select_experiment(results, i):
    df = pd.DataFrame(results[i - 1]['result'])
    directory = './experiment_%s/' % i
    if not os.path.exists(directory):
        os.makedirs(directory)
    return df[df.substep==len(partial_state_update_blocks)].copy()

def save_experiment(fig, experiment, name):
    pickle.dump(fig, open('experiment_%s/%s.pickle' % (experiment, name), 'wb'))
    fig.savefig('experiment_%s/%s.png' % (experiment, name))
```

```
rdf = select_experiment(results, 1)
network_output = rdf['network'][24]

pos = nx.drawing.nx_agraph.graphviz_layout(network_output, prog='neato') #spring_layout(network, k=0.15,it

node_sizes = [50 if network_output.nodes[node]['_type'] == Nodes.PARTICIPANT.name else 800 for node in net

plt.figure(1,figsize=(20,10))
nx.draw(
    network_output, pos, edge_color='black', width=2, linewidths=1,
    node_size=node_sizes, node_color='pink', alpha=0.9,
    labels={node: node for node in network.nodes()})

nx.draw_networkx_edge_labels(
    network_output, pos,
    edge_labels={(u,v): d['_type'] for u,v,d in network.edges(data=True)},
    font_color='red')
```

```
plt.axis('off')
plt.show()
```




```
for experiment in params['sweep']:
    rdf = select_experiment(results, experiment)
    rdf['IXO_pool_growth'] = rdf['network'].apply(lambda g: get_pool_balance(g, 'IXO'))

    fig = plt.figure(1,figsize=(20,10))
    #data = make2D('IXO_pool_growth', rdf)
    plt.plot(rdf.timestep, rdf['IXO_pool_growth'])
    plt.title('IXO pool growth')
    plt.xlabel('time ($months$)')
    plt.ylabel('balance ($tokens$)')

    save_experiment(fig, experiment, 'IXO_pool_growth')
```




```
for experiment in params['sweep']:
    rdf = select_experiment(results, experiment)
    rdf['DAI_pool_growth'] = rdf['network'].apply(lambda g: get_pool_balance(g, 'DAI'))

    fig = plt.figure(1,figsize=(20,10))
    #data = make2D('IXO_pool_growth', rdf)
    plt.plot(rdf.timestep, rdf['DAI_pool_growth'])
    plt.title('DAI pool growth')
    plt.xlabel('time ($months$)')
    plt.ylabel('balance ($tokens$)')

    save_experiment(fig, experiment, 'IXO_pool_growth')
```