Running Osrank on a blockchain

An informal specification

Di Napoli, Alfredo
alfredo@monadic.xyz

Breitkreuz, Merle
merle@monadic.xyz

July 2019

Contents

1 Introduction

Osrank is at the heart of the *Oscoin* vision, and is formally defined as *[..]a variant of the well known PageRank algorithm, applied to the graph of relationships between projects and contributions on the network[..]to choose which project receive oscoin and in which proportions.*[1]

This document tries to bridge the gap between the theoretical aspect of the paper and the practical one, describing possible ways to implement and run *Osrank* on a blockchain.

2 User scenarios and requirements

In this section we present a possible list of user scenarios and requirements for *Osrank*, some of which might fall "in between" the *Osrank* and *Oscoin* projects, but are nevertheless shown here to get a firmer understanding of the context we are operating in.

2.1 User scenarios

In this section, a number of very **high level** user scenario are presented. They are vague on purpose; the main aim here is not to figure out how to do things from a technical perspective, but more to give an eagle-eye view of how the system should behave.

2.1.1 Scenario: Node computes Osrank every epoch

1. Every *epoch*, i.e. every k blocks, the system runs the *Osrank* algorithm.
2. The system gathers the *hyperparameters* and the *damping factors* on-chain, from the ledger state.
3. The system loads the actual network graph from an off-chain storage, and executes the *Osrank* procedure on it.
4. Each node in the *network graph* has its *Osrank* weight (re-)calculated.
5. A new transaction is created within the system that distributes funds from the *Oscoin treasury* to the *graph nodes*, in quantity proportional to their *Osrank*.

2.1.2 Scenario: Oscoin node receives new block with Osrank transaction

Nota bene: We are not going to discuss and address forks in this scenario, as they simply revert state. We focus on the most common scenario.

1. A node N receives a new block B from the network directly extending N's adopted chain and therefore forming the new tip;
2. N verifies each and every transaction in B;
3. If one of the transactions tx is a *Osrank* one, the node verifies the generated *Osrank* is valid by re-running the same computation in a verifiable way;
4. If the verification succeeds, N adds block B as the new tip;
5. If the verification fails, N discards the block B as it comes from a potentially malicious network operator.

2.2 Performance requirements

1. The entire *Osrank* algorithm *must* run in much less than the *block time*, where for *Oscoin* this is set to *60 seconds*. A good conservative threshold is for the algorithm to run in *50%* of the total block time, to make sure the network operator's node has time to also perform other operations, remaining within the same boundary of the block time. [Time]
2. The performance of the *Osrank* algorithm shall be as much as possible independent from the *size* of the network graph. In other terms, having the performance of the algorithm be linearly dependent from the size of the graph will make it eventually surpass the *block time* hard limit. [Time]

3. The memory allocation of the *Osrank* algorithm must be such that it's possible to run the algorithm on most personal computers and other devices with limited memory. As most devices these days tends to have a RAM of *8 GB*, this seems to be a hard limit. [Space]

2.3 Ledger interface requirements

1. It shall be possible to retrieve the *hyperparameters*, *damping factors* and the values for R and τ from the *Ledger* state, where R is the number of random walks to perform for each node n and τ is the pruning threshold for the first phase of the algorithm. [Functional]

2. It shall be possible to update the *hyperparameters*, *damping factors*, R and τ if needed (i.e. during a *soft fork*). [Functional] **UPDATE**: This is not relevant to *osrank* directly, but obviously it should be possible to update the parameters after *mainnet*.

3. If the number of blocks k that determines the length of an *epoch* are fixed, it shall be possible to get and set k from the *Ledger* state. [Functional] **UPDATE**: This is now stale. This was useful for an approach where we would "weight" the contributions based on the age of those (for which we would have needed the k), but this has now been abandoned.

2.4 Graph API requirements

Nota bene: This section does not include Ledger-side requirements, i.e. it doesn't list things like adding/removing nodes or edges from a network graph, because the *Osrank* algorithm is only concerned with updating certain *metadata* of a given network topology. The full list of requirements for the *Graph API* is probably the union of the *Ledger requirements* and the requirements in this document.

1. It shall be possible to execute the *Osrank* algorithm on a particular *network graph* with any extra state correctly passed to it (e.g the cached *random walks*). [Functional]

2. It shall be possible to modify the weights associated to each *edge*, as more *projects* or *accounts* gets added. [Functional]

3. It shall be possible to retrieve the *neighbours* associated to a particular node in a *network graph*. [Functional]

4. It shall be possible to generate a random-yet-predicable *seed* to be used to instantiate a *PRNG* from the *Osrank* algorithm, so that the latter is fully deterministic and verifiable. [Functional]

5. (**n.b. Is this a Ledger requirement instead?**) It shall be possible to retrieve, given a $(k1, k2)$ epoch *range*, all the additions/deletions to the network graph, so that *Osrank* can use them for the incremental algorithm. [Functional]

2.5 Storage requirements

1. It shall be possible to retrieve a *network graph* given a unique identifier. [Functional]
2. A *network graph*'s size should not exceed the memory hard limit as described in the *Performance Requirements*. [Space]

3 Challenges and unknowns

3.1 Who runs the osrank calculation?

Status: **Resolved**

Option 1: Native code all the way down

If this is run by each and every network operator in the system, the only way to prevent cheating is to have each node in the network validate the output of the *osrank* algorithm by re-running it against the same state from which a received block B has been created. This also assumes that the algorithm is cheap to compute. Once the osrank has been calculated, the result must be included in the new block being mined, alongside with one or more transactions to distribute the payouts. Here the network operation might need to call into a smart contract to actually validate the reward transaction, because he/she wouldn't have the private key to authorise spending from the treasury, so that needs to come from a "pre-baked" smart contract.

Advantages

1. Running everything via native code means tapping into the full potential of a node;
2. No artificial boundaries: hyperparameters & damping factors are just integers/floats, and they are easy to fetch and deserialise from the state store, even across an artificial WASM boundary, if any;
3. All the queries on data can happen off-chain, without crossing the WASM boundary.

Disadvantages

1. Not clear how to validate the reward transaction;
2. If the *osrank* computation is not cheap, re-running it for validation purposes might be prohibitive.

Option 2: WASM code all the way down

If the osrank algorithm is run on-chain, then the tempting avenue is to have the osrank algorithm be implemented as a WASM blob/smart contract, which is baked in the genesis block and can be updated via forks. In this scenario users would create a new transaction every *epoch* (e.g. k slots) targeting the smart contract address.

Advantages

1. Clearer semantic as everything is a smart contract;
2. Generalising this to a graph-ledger might fit naturally within this framework;
3. No need to worry about cheating;

Disadvantages

1. We might need a gas-model;
2. We might hit a performance bottleneck when running the algorithm via WASM;
3. Crossing the WASM boundary might be tricky to implement;

Resolution

Out of scope. The scope of this document shouldn't be concerned about technical, implementation details like WASM. For *Osrank* is sufficient to know there is a Graph API we can call and that we can rely on the Ledger to mine a block with the payout.

3.2 How to generate randomness?

Status: **Open**

In [1], a modification of the algorithm is proposed, in order to make it resistant to *sybil attacks*. Such modification involves using a trusted *seed set* from which all the random walks needs to begin (during the first phase of the algorithm). On top of this, every time the algorithm visits a node, it has to pick which vertex to visit next based with a certain probability. In other terms, at every step the algorithm needs to roll a dice which outcome is biased by the probability on each edge, but ultimately this step still involves a degree of randomness.

Random functions can usually be seeded which an initial value, in order to make their evolution deterministic: given an initial seed value, a function *rand(seed)* will produce a random value alongside a new seed, to be used in the next call to *rand*.

This naturally give raise to a question: *how to seed the algorithm in a blockchain context?* Ideally we want to make the output of the algorithm verifiable and replicable (for obvious reasons) but we do not want adversaries to be able to "guess" the random walks before the algorithm will actually run.

One possibility as discussed within the team might be to use something like the hash of the last k-blocks to generate a seed, but a bit more research needs to happen around the robustness of this approach from a *game theory* perspective: a user might deliberately try to generate a different seed to generate an *Osrank* which is advantageous to him.

Possible Resolution

Alexis will own this.

3.3 Is there an initial `SeedSet` at genesis?

Status: **Resolved**

One key characteristic of the `SeedSet` is that it's composed by a *trusted* and *curated* collection of projects & accounts from which the random walk can be initiated. Therefore, this set must necessarily be assembled by a trusted party (i.e. like the members of the *oscoin* project) and distributed on-chain via the genesis block.

Resolution

Due to the fact the initial set of projects will be limited to the ones that decide to be early adopter of *Oscoin*, the process could be curated by *Monadic GmbH* itself.

3.4 Do we need to update the `SeedSet` periodically, and how?

Status: **Resolved**

The main insight behind the *seed set* is to make sure eventually the random walks explore the totality of the network graph, including disconnected components. It's conceivable that as more projects gets added, the more the initial *seed set* will be out-of-date, and in need of an update.

Resolution

Out of the scope.

3.5 Should we store `R`, `k` and the `TrustRank` threshold on the Ledger?

Status: **Resolved**

In the incremental MonteCarlo implementation, the parameter R is used as a coefficient to calculate the final rank, in the approximated formula. Conversely, we define that the system enters a new *epoch* every k blocks. Last but not least, *TrustRank* (from which the *seed set* idea is taken) uses a *threshold* parameter to prune the initial network graph before running the "real" algorithm.

Should we store these parameters on the Ledger or should these be hardcoded?

Resolution

On Ledger, not sure yet about k but not relevant for Osrank team we will have this info.

3.6 Is there an initial network graph at genesis?

Status: **Resolved**

If there is an initial seed set, it's quite likely there will be an initial network which will be baked into the genesis block. Not doing that means that there will be some project/accounts in the seed set referencing non-existing nodes inside the network graph, and this could potentially be an invariant violation, as the *TrustRank* algorithm requires the seed set to reference valid nodes.

Are we OK with a genesis block which could be potentially hundreds of megabytes?

Resolution

We won't need to include entire ecosystems into genesis, but likely only the number of projects and accounts which would sign as early adopters. This means that, in practice, the initial network graph, especially if compressed, shouldn't be too big, probably in the ballpark of 3-4 MB, if we consider the possibility to add *metadata*.

3.7 How can a network operator verify the osrank (incremental) computation without the remote's cached random walks?

Status: **Resolved**

One of the suggested improvement described in [1] is the use of an incremental algorithm based on the work of [2]. This algorithm uses a set of cached random walks to compute the osrank incrementally and in a fast manner. However, this poses a challenge for *verifying* the algorithm, because the set of cached random walks of the *verifier* will be probably different from the one of the node which originally computed the osrank.

One obvious solution would be to *store the set of random walks on chain* as part of the output of the osrank calculation, assuming the size of such walks is such that storing this as part of the Ledger state is feasible.

Resolution

If the algorithm is deterministic and it is seeded with a PRNG, and all miners use the same source of entropy, then theoretically the set of random walks should be predictable and deterministic as well. In terms of *where* to store the cached information, the most feasible place is on secondary memory (i.e. disk), as doing so on the *Ledger* would take too much space. Note that this means that network operations might miss some information if they have been offline for too long or simply new to the network. In either cases, the node syncing algorithm can solve both concerns: during syncing a set of random walks would be generate every *epoch*.

N.B The cache/storage will need to be thought through (possibly between Osrank & Protocol team).

3.8 How to distribute oscoin to accounts in a graph?

Status: **Resolving**

The paper computes the *osrank* for projects *and* accounts, so it might seem spontaneous to include some form of payouts to these accounts as well, as "influential" members of the network. If this is a viable venue, then the shape of a reward transaction should be different from the one described in the paper, which distributes funds associated to a project's smart contract.

Resolution: Ledger & Protocol team will design this & will require Osrank to somehow either supply these rankings out of the algorithm calculation or as part of the storage.

3.9 What is the shape of an osrank transaction?

Status: **Resolved**

A question which arise spontaneously is how big an "osrank transaction" should be. Ideally speaking, once the *osrank* has been calculated (for each project in the network) such up-to-date values are transmitted on-chain by forging a new, big transaction which informs the ledger that the osranks have changed. If this is true, how big such transaction will be? The number of projects and accounts is unbound, so the size of such transaction will grow linearly with the size of the ecosystem, which is not ideal.

Resolution: no need for transaction because the concept of osrank is intrisic to the protocol.

3.10 What is the shape of a reward transaction?

Status: **Resolved**

Similarly to the question above, a genuine question is what should be the shape of a reward transaction. According to [1], there should be "[..]a reward in *oscoin* which is derived from each project's *osrank* and distributed via the project's associated smart contract[..]"

This seems to suggest the existence of a single, enormous transaction where the *inputs* are the smart contracts of each project in the network (for which the *Osrank* has been computed) and as output the output of these contracts, which is one or more *addresses* that will need to receive *oscoin*. How big such transaction will be?

Resolution

Although it's not fully clear how things will work on the smart contract/ Ledger side (but that's outside the scope of this document) in the implementation there

will be no *treasury* in the common Blockchain sense, but rather the *coinbase reward* B_r will be bigger every k blocks (i.e. bigger for the block in which the *Osrank* is (re-)calculated) which will avoid any complication stemming from implementing a proper *treasury*.

3.11 Where to store the cached random walks?

Status: **Open**

In [2], the random walks were stored in an ad-hoc, in-house NoSQL graph database (i.e. *FlockDB*, now unmaintained). We should discuss storage options.

Possible resolution

Neo4J or custom storage? Requires more research.

3.12 How to deal with the Graph's disconnected components?

Status: **Resolved**

The full network graph is, in reality, composed by a certain number of disconnected components. Think, for example, to a "Haskell" component and a "Rust" component: even though some 'Account' might be contributing to projects in both ecosystems, it's likely that the Rust's projects and Haskell's project won't have a single link between them. This poses a number of interesting questions:

1. How does this influence the random walks?
2. Hoes does influence the final *Osrank* calculation? How much does it "dilute" it?

Possible resolution

In theory disconnected components shouldn't be a problem. The initial walk originated from the seed sets should help cutting nodes which have a way-too-low *Osrank* so that the will receive an *Osrank* of 0 at the end. This will help with the "dilution".

3.13 Should $Osrank$ be modeled as a f64?

Status: **Open**

In order to verify the *Osrank* calculation, it's paramount that all the network operators (re)running the algorithm would get the same result, which means the same (updated) set of random walks and all the ranks. However, if the *Osrank* is calculated as a floating point (i.e. a Rust 'f64') this might be problematic / bordeline dangerous for two reasons:

1. Apparently IEEE floating point numbers are interpreted differently according to different architectures;
2. We might be subject to rounding errors, so the final probability distribution won't sum to 1.0 eventually.

To demonstrate this is a concern, the IOHK folks wrote a specification on how to deal with non-integral calculations.

Resolution

None yet. Exploring posits might be interesting. There is also a review from INRIA. The downside of *posits* seems to be that the precision depends on the scale of the operations. This might pose a problem for things like *Osrank* itself, which is modeled as a probability distribution.

3.14 What should happen if a completely isolated node is added to the graph?

Status: **Resolved**

The incremental Monte Carlo paper defines the approximated *PageRank* this way:

$$\pi_u = \frac{X_u}{\frac{nR}{\epsilon}}$$

This technically means that from a mathematical standpoint, if n grows (because a new node has been added to the graph) then the rank for *all* the affected nodes will need to change. However, from an intuitive point of view, when adding a new project, if this project doesn't have any incoming edges, it means it has no value for the community. Not only that, but it could be effectively used as an attack vector, to slow down the overall *Osrank* calculation. However, the *pruning* via the *seed set* will ensure that eventually these new node is disregarded during the real calculation, as its rank is 0 and therefore it doesn't meet the threshold requirement.

Resolution

Osrank is set to 0 for those, and we can skip it. Insight: if a node is not connected to one of the seed set nodes is not reachable.

3.15 Should we have to deal with the added complexity of multiple project versions?

Status: **Open**

The *Osrank* algorithm runs under performance hard-limits (i.e. time to compute way less than the *block time*) and therefore anything which adds complexity should be avoided. More specifically, incorporating the concept of project versions poses quite a few challenges to the *Osrank* team:

1. If a project has on average 10 versions (and that's optimistic) we might be looking (in the worst case scenario) to a 10x increase in the graph size, even though is conceivable most projects would depend only from the top 3-4 newest project versions.
2. The *Osrank* incremental algorithm needs to (re)compute the random walks every time an edge is added *or* removed from the graph: not *all* the walks need an update, but only for the ones for which contained the updated node (i.e. a node "impacted" by the edge removal). If we allow checkpoints to take into account versions, upon a version dump it's conceivable three things are going to happen: a new node (for the version) is added (either at checkpointing or previously), a new edge is created from the project to the *new* version and an edge is *removed* from the project to the old version. This might create more work for the *Osrank* algorithm, which might make it exceed the hard-limit threshold.

Resolution

None yet.

4 The Osrank Basic Model

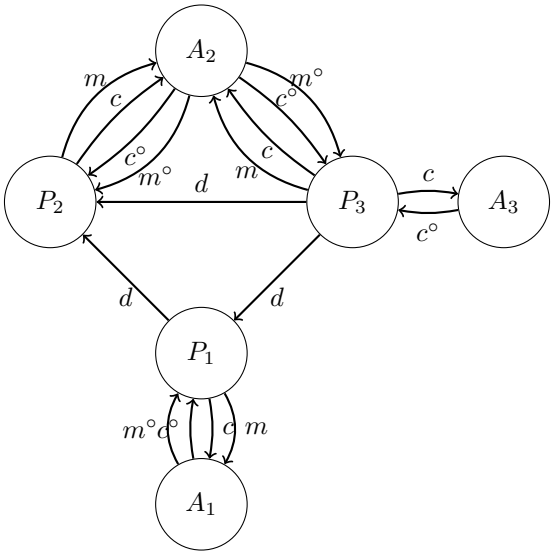
This section outlines the basic *osrank* model described in the oscoin whitepaper http://oscoin.io/oscoin.pdf in a more practical way to create a common understanding of its functionality. In particular it documents how the adjacency matrix is constructed which then can be fed into a PageRank algorithm. The

latter will (for now) not be described in detail. At a later point this document should be expanded to describe the full *osrank* algorithm.

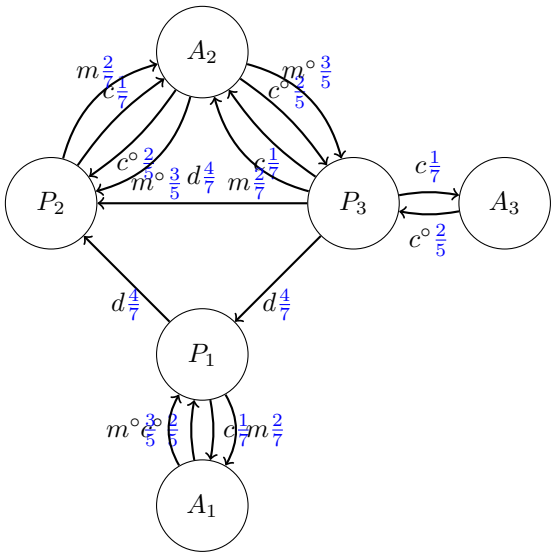
4.1 Create the adjacency matrix

4.1.1 By-hand via-graph approach

We start with a directed graph of projects P and Accounts A. Dependencies (depend/d) are edges between projects. Edges between accounts and projects are always in both directions. They represent contributions (contrib/c) and maintainers (maintain/m).

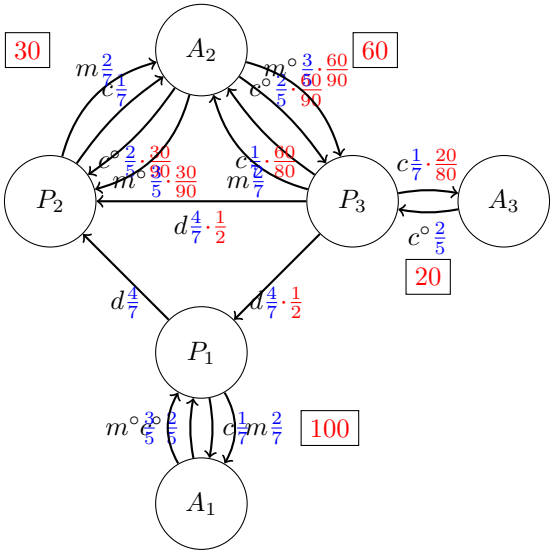


In the first step, each edge will be weighted according to their type.

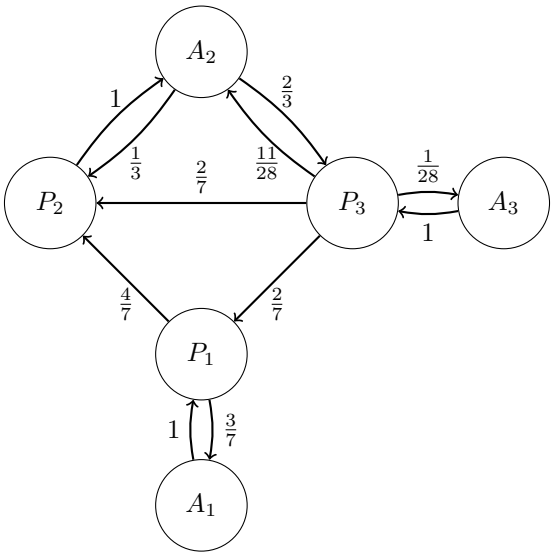


edge type	value
depend	$\frac{4}{7}$
contrib	$\frac{1}{7}$
maintain	$\frac{2}{7}$
contrib°	$\frac{2}{5}$
maintain°	$\frac{3}{5}$

The whitepaper then suggests to adjust these weights again. The values of *depend* and *maintain* are each divided by the corresponding count of outgoing edges of the same type on the node. *contrib*° and *maintain*° are multiplied by the number of contributions of the account to the project, divided by the total number of contributions of the account. *contrib* is multiplied by the number of contributions of the account to the project, divided by the total number of contributions in the project.
In the graph below, information about the number of contributions for each connection is represented by the red number in the squares. Factors of value 1 are omitted. This occurs if the node has only one outgoing edge of the same type.



Finally we want to reduce the graph to single edges only, so *maintain* and *contrib* and *contrib*$^\circ$ and *maintain*$^\circ$ are summed up. The weights of outgoing edges are then normalized per node to ensure that all outgoing edge weights of one node add up to 1.



The final graph can be represented in a adjacency matrix.

	P_1	P_2	P_3	A_1	A_2	A_3
P_1	0	$\frac{4}{7}$	0	$\frac{3}{7}$	0	0
P_2	0	0	0	0	1	0
P_3	$\frac{2}{7}$	$\frac{2}{7}$	0	0	$\frac{11}{28}$	$\frac{1}{28}$
A_1	1	0	0	0	0	0
A_2	0	$\frac{1}{3}$	$\frac{2}{3}$	0	0	0
A_3	0	0	1	0	0	0

4.1.2 Via-dataset approach

For this approach we divide the final adjacency matrix into 4 quadrants and calculate each quadrant separately.

$$\left(\begin{array}{c|c} P \to P & P \to A \\ \hline A \to P & A \to A \end{array}\right)$$

We start off with 3 matrices constructed out of provided data. Note that the order of projects and accounts has to be consistent for each matrix. D is the dependency adjacency matrix with values 0 or 1 representing dependencies of projects. C is the contributions adjacency matrix with values 0 or the number of contributions the account made to the specific project. M is the maintainers adjacency matrix with values 0 or 1. For C and M the rows represent the projects and the columns the accounts.
For the example above, the matrices would look like this:

$$D = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{pmatrix}, C = \begin{pmatrix} 100 & 0 & 0 \\ 0 & 30 & 0 \\ 0 & 60 & 20 \end{pmatrix}, M = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

These adjacency matrices together with the initial and additional factors are then used to calculate the quadrants. The $A \to A$ quadrant is just a matrix of zeroes as there are no connections between accounts.

$$\begin{aligned} P \to P &= d \cdot norm_{row}(D) \\ P \to A &= m \cdot norm_{row}(M) + c \cdot norm_{row}(C) \\ A \to P &= ((m^\circ \cdot M^T) \odot norm_{row}(C^T)) + c^\circ \cdot norm_{row}(C^T) \end{aligned}$$

where $\odot$ is the Hadamat product and $norm_{row}$ is the row-wise normalization. Combining all quadrants as represented above and applying $norm_{row}$ again to the final matrix, results in the same adjacency matrix as at the end of the last section.

4.2 Customized PageRank

4.2.1 Naive Osrank

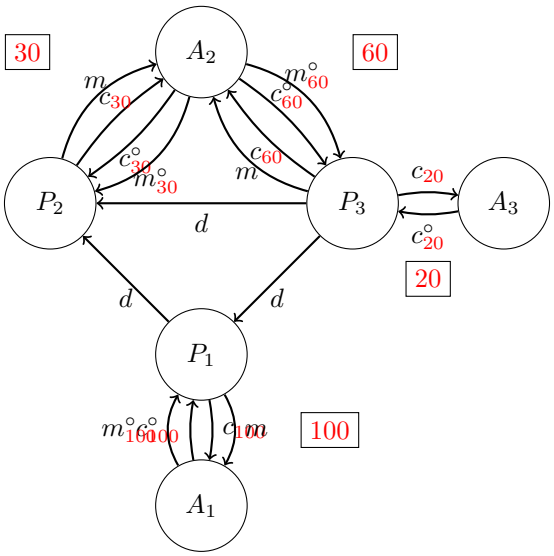
The static *osrank* model runs a customized PageRank algorithm on the weighted directed graph constructed in the last section. The only customization for now is the addition of damping factors. The factor is the probability that a random walk will continue. For *osrank* we distinguish between damping factors for projects $\epsilon_{project}$ and accounts $\epsilon_{account}$. So for example $1 - \epsilon_{project}$ refers to the probability that the random walk will terminate on a project node.
The values for the factors were not further specified in the whitepaper, for classic PageRank implementation often a damping factor of 0.85 is used.

4.2.2 Monte Carlo Random walks

In this approach the *osrank* is calculated by doing R random walks starting from each node of the graph. The rank for a node x is then derived by:

$$\omega(x) = \frac{W_x(1 - \epsilon_{node})}{nR}$$

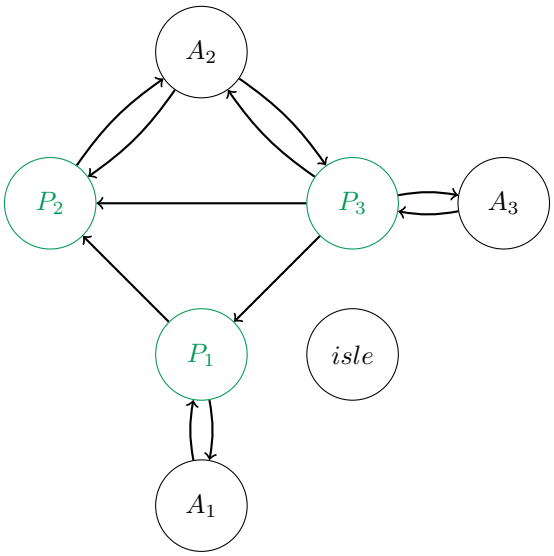
where n is the number of nodes in the graph and W_x is the number of visits to x of all random walks.
The random walks can either be made on a pre-weighted graph as described above, or weighing the edges can happen on the fly while walking on the graph. For this, the graph has to be constructed slightly different, which will be described here.
In this graph, edge types are not collapsed into each other to end up with a graph with single edges as above. Here, each node has at most one edge of the same type. The number of contributions which influences the weights of c, c° and m° is stored in counters on those edges. d and m do not need counters.



To choose the next node for the random walk from node N_i, first the type of edge is chosen, weighted by the hyperparams. Then for d and m the next edge is chosen equiprobable. For c, c° and m° each edge is weighted by the number of contributions of the edge, normalized by the total number of contributions of N_i. (Note: *SliceRandom* :: *choose_weighted* in Rust normalizes all weights, so that passing the counter for each edge is sufficient.)
This means that the graph does not need to be preprocessed to calculate the weights and has advantages for updating the graph which will be described below.

4.2.3 Seed set Phase

This approach tries to ensure that only trusted nodes receive an *osrank*. For this a seed set S of nodes of the graph is provided and trust is determined by the accessibility of nodes from the seed set.
For this approach the algorithm has two phases of calculating ranks as described in the last section. In the first one, which we will call *seed set phase* the random walks only start on the seed set nodes. The ranks are then calculated as described above. Only the nodes which ranks pass a fixed threshold τ are eligible for receiving *osrank*. A subgraph on those nodes is then passed to the second phase, where the random walks start form each of the subgraph.
To demonstrate this approach, we'll look at the sample graph and add another node *isle* which has no edges. Our seed set are the projects 1 to 3 (marked green).



Running the algorithm without a seed set phase on this graph, i.e. all nodes are starting nodes for the random walks, would give *isle* an osrank of $\frac{R(1-\epsilon_{node})}{nR}$. Note that here n is the number of nodes in the full graph. With the seed set phase though, *isle* will never be visited by the random walks starting from the seed set nodes and receiving a rank of 0. With $\tau > 0$ *isle* will not be eligible to receive *osrank* in and thus not included in the subgraph for the second phase.

4.2.4 Incremental algorithm

The following section is work in progress and has not been implemented yet.
Instead of recalculating all *osrank*s whenever the graph changes, this approach only recalculates the ranks for the nodes that are influenced by the changes. Changes to the graph can be addition or removal of a node or edge.

1. **Adding a node** without any edge has no effect on the ranking of other nodes and the new node does not receive any ranking, i.e. adding a node has no effect on its own. (Note: This is currently under discussion and might also be influenced by decisions around the seed set approach. In theory an added node increases n and thus influences the *osrank* of all nodes, but if added during the seed set phase this isolated node would be not considered for *osrank* in the second phase).
2. **Removing a node** influences the *osrank* of all nodes. This is due to the fact that on the one hand after the removal the number of random walks is reduced by R and n by 1, on the other hand, all random walks that

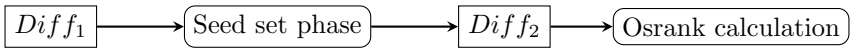
visited the removed node This is due to the fact that on one hand, after the removal, the number of random walks is reduced by R and n by 1, but on the other hand, all random walks that visited the removed node are invalidated.

3. **Adding/Removing an edge** influences the graph depending on the type of edge. For a changed dependency, random walks visiting the starting node of the edge are invalidated. For contribution and maintenance edges, random walks visiting both the start and end node are invalidated due to their bi-directional nature.

If a change is applied, all invalidated random walks are removed and all nodes visited by them are registered for *osrank* recalculation. The random walks for each node are filled up to R again and all visited nodes are registered for recalculation as well. In the end for each node registered for recalculation, the visits are counted and the *osrank* is calculated again.

4.2.5 Combining the seed set phase and the incremental algorithm

The following section is work in progress and has not been implemented yet.
When combining these two approaches, the changes have to be applied to both phases. We therefore distinguish between the changes that are passed by the ledger which are applied in the seed set phase and the changes that are passed by the seed set phase to the second phase. This means that we will have to store two sets of random walks, one for each phase.



$Diff_1$ has the following change events that are similar to the ones described in the last section with some additions. We distinguish here between simple and seed set nodes, i.e. nodes are simple as long as they are not in the seed set.

1. **Adding a simple node** has no effect as this event does not add edges. An isolated node can't be reached from the seed set.
2. **Adding a node to the seed set** increases n and leads to R additional random walks. All ranks have to be recalculated. (*Note:* Adding the node itself and its edges are different events and precede this event.)
3. **Removing a simple node** invalidates all random walks that visited this node. In addition all its edges lead to *remove_edge* events.
4. **Removing a node from the seed set** decreases n and all random walks visiting this node are invalidated. All ranks have to be recalculated.

5. **Adding an edge** see previous section. (*Todo:* The amount of work can potentially be reduced here by analyzing how additional edges actually affect the random walks. For example, if both endpoints did not receive rank above the threshold before, can the added edge change this?)

6. **Removing an edge** see previous section.

$Diff_2$ consists of the following changes:

1. The changes from $Diff_1$, if the concerning nodes are eligible for *osrank* calculation. The events adding or removing a seed set node are not included in $Diff_2$.

2. Any node that is newly eligible for *osrank* is included as a *add_node* event. In addition its edges (if both endpoints are eligible for the second phase) are included as *add_edge* events.

3. In parallel to the last point, any node that is newly non-eligible for *osrank* are included as *remove_node* and hence *remove_edge*.

4.3 Open questions

1. The model assigns ranks to projects and accounts, but the distribution is only meant to be for projects. Should the ranks be normalized again over all projects? Which rank will be shown to the user?

2. Can a project lose its osrank all altogether? (This might happen due to the seed set phase)

5 The Osrank algorithm

This section describes a possible interface for the *Osrank* algorithm. If we were to give *Osrank* an abstract formulation using Rust's traits, a plausible interface could look like this:

```
// Definition omitted. The real implementation will likely
// be more complex than this, but somehow it should always
// be possible to get an ID out of either a node or an edge.
trait Graph{
    type NodeId;
    type EdgeId;
}
```

```
trait LedgerView{}

trait GraphAlgorithm<'a, G:Graph, L:LedgerView, RNG: 'a> {
    type Input;
    type Output;
    type State;

    /// Access any state necessary for this algorithm to run.
    fn get_state(&self) -> Self::State;
    /// Execute the algorithm.
    fn execute(self, graph: &G, ledger: &L, input: &Self::Input) -> Self::Output;
}
```

Assuming the existence of a sound implementation for the `Graph` and `LedgerView` traits, the *Osrank* implementation could then look like this:

```
enum MockGraph { MockGraph }
enum MockLedger { MockLedger }
enum Osrank{ Osrank }
type CachedRandomWalks = ();

impl Graph for MockGraph {
    type NodeId = ();
    type EdgeId = ();
}

/// What's changed in the `Graph` respect to the previous invocation of the
/// algorithm.
enum GraphDiff<'a, G: Graph + 'a> {
    NodeAdded(&'a G::NodeId),
    NodeRemoved(&'a G::NodeId),
    EdgeAdded(&'a G::EdgeId),
    EdgeRemoved(&'a G::EdgeId)
}

/// A simplified walk, which implementation is likely to be a bit more
/// complicated than this.
struct Walk<'a, G: Graph + 'a> { walk: Vec<&'a G::NodeId> }

/// A type isomorphic to patch theory edit (See:
/// http://hackage.haskell.org/package/patches-vector-0.1.5.4/docs/Data-Patch.html#t:Edit)
enum WalksDiff<'a, G: Graph + 'a> {
    /// A new walk has been added.
    WalkAdded(&'a Walk<'a, G>),
    /// The walk at index `usize` has been removed.
```

```
    WalkRemoved(usize, &'a Walk<'a, G>),
    /// The walk at index `usize` has been replaced.
    WalkReplaced{ position: usize, old: &'a Walk<'a, G>, new: &'a Walk<'a, G> }
}

struct OsrankInput<'a, G: Graph + 'a, RNG> {
    rng: &'a mut RNG,
    graph_diffs: &'a Vec<GraphDiff<'a, G>>
}

struct OsrankOutput<'a, G: Graph + 'a> {
    ranking: RankIterator,
    state_diff: &'a Vec<WalksDiff<'a, G>>
}

struct RankIterator{} //implementation omitted

impl<'a, G: 'a,L,RNG: 'a> GraphAlgorithm<'a, G,L,RNG> for Osrank
where
  L: LedgerView,
  G: Graph  {
    type Input  = OsrankInput<'a, G, RNG>;
    type Output = OsrankOutput<'a, G>;
    type State  = CachedRandomWalks;

    fn get_state(&self) -> Self::State {
        unimplemented!()
    }

    fn execute(self, graph: &G, ledger: &L, input: &Self::Input) -> Self::Output {
      unimplemented!()
    }
}
```

Ignoring the dummy types, here are the key ideas:

1. A source of randomness is provided to the algorithm via the `RNG` type parameter, but it's not a requirement for algorithms to use it. In the case of *Osrank* though it is indeed needed, so we must pass it as an `Input`.
2. Everything is immutable, including the result, that includes some notion of *state difference*, without actually mutating it.
3. The `Output` of the `GraphAlgorithm` could also include a data structure that implements the `Iterator` trait, so that upper layer could stream the results efficiently. In the example, `RankIterator` is such data structure.

5.1 The cached random walks

The `GraphAlgorithm` trait defines an associated `State` type which, in the concrete implementation, is set to be `CachedRandomWalks` (for simplicity, aliased to `()`). The notion of *random walk* is crucial in the *incremental Monte Carlo* algorithm [2], as it's the key to compute the *Osrank* algorithm efficiently. An initial intuition is given by the *whitepaper* [1] directly:

"[..]Instead of computing *Osrank* from scratch, we rely on the fact that only a small percentage of vertices or edges are added or removed from one calculation to the next. Therefore, most of the random walks performed in the previous calculation remain valid in the updated graph[..]".

This is the reason why we introduce the `GraphDiff` enumeration: in order to work properly, the *Osrank* algorithm needs to know, between executions, if the network graph changed and how, in order to be able to recompute only the random walks affected.

Defining a precise shape for the `CachedRandomWalks` might be outside the scope of this document. What we can do, though, is to spell out some key characteristics this data structure should have:

- Given a `NodeId` identifying a node u, it should be possible to efficiently retrieve the *number of visits* X_u for the node u, i.e. the number of times all the random walks visit u, in total;
- Given a now-deleted node u identified by its `NodeId`, it should be possible to efficiently retrieve *and update* the random walks which visited u. This is because now any random walk visiting u cannot visit this node anymore, and thus the random walk *will* change;
- Given a newly added edge (u, v), it should be possible to efficiently retrieve *and update* all the random walks that visits both u and v. This is because now any random walk passing for u or v could pick this edge, and thus the random walk *might* change;
- Given a now-deleted edge (u, v), it should be possible to efficiently retrieve *and update* all the random walks that visits both u and v. This is because now any random walk passing for u or v cannot pick this edge anymore, and thus the random walk *might* change;

5.2 Mutating the `Graph` to recalcutate the weights

The current trait doesn't allow the `Graph` to be mutated during execution, which can be both a good and a bad thing. It's a good thing as it helps reasoning

about the execution and the algorithm and gives the caller the guarantee that the `Graph` won't be modified under the hood, but it's a bad thing as it stops the algorithm from updating the weights associated to the edges and to add new nodes to the `Graph`. There are two obvious solutions to this:

1. The `execute` function should be given a `&mut` reference to the `Graph`, so that it can mutate it.
2. The *execution* of the algorithm to compute the rank should be separated from the *normalisation* of the `Graph`, which suggests the existence of a function to be called before `execute` that does modify the `Graph`. [1]

5.3 Separating execution from normalisation

The previous section calls for a separate function which would mutate an input `Graph` and perform a number of things:

1. Update any relevant *weights* for edges which were either added or indirectly updated;
2. Normalise the *Graph* so that any parallel edges (for example the ones related to contributions, maintenance or even project versions) would be collapsed in a suitable format for the *Osrank* algorithm, which needs to work with only one outgoing edge between two nodes;

This could be achieved with another trait, like the following:

```
trait MutableGraphAlgorithm<'a, G:Graph, L:LedgerView, RNG: 'a>:
  GraphAlgorithm<'a, G,L,RNG> {
    fn normalise(self, graph: &mut G, ledger: &L, input: &Self::Input);
}
```

There is a big advantage with this approach which might not be immediately evident: by separating these two traits, we can ensure that the `MutableGraphAlgorithm` stays internal to the `Graph API` and/or the *Osrank* project, and the `GraphAlgorithm` is exposed to any third-party code wanting to run computation over a `Graph` without mutating it.

[1] The author is obviously biased by his *Haskell* heritage.

5.4 Optimisations

There are a number of optimizations we can perform over the original *incremental Monte Carlo* algorithm, in order to avoid work.

1. Ignore disconnected nodes

If a new node is added, and such node doesn't have any incoming edges, it means that it cannot be reached from any of the random walks, *unless* this node is part of the nodes in the *seed set*. If a node cannot be discovered, it means it provides no value to the open source ecosystem, and therefore it shouldn't be entitled to any *oscoin* payment during the *payout* phase. This translated directly with an *Osrank* of 0.

In other terms, if a node is not reachable from one of the *seed set* vertexes, it can be ignored, and the algorithm shouldn't be (re)run if such node is added to the graph.

6 Conclusion

TBD.

References

[1] Sellier A., Diakomichalis E., and Haydon J. Open source coin: Trust and sustainability in open source communities. Technical report, Monadic GmbH, 2019.

[2] Bahman Bahmani, Abdur Chowdhury, and Ashish Goel. Fast incremental and personalized pagerank over distributed main memory databases. *CoRR*, abs/1006.2880, 2010.