

Psamathe: A DSL for Safe Blockchain Assets

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ABSTRACT

Blockchains host smart contracts for crowdfunding, tokens, and many other purposes. However, vulnerabilities in contracts are often discovered, leading to the loss of large quantities of money. Psamathe is a new language we are designing around a new flow abstraction, reducing asset bugs and making contracts more concise than in existing languages. We present an overview of Psamathe, and discuss two example contracts in Psamathe and Solidity.

1 INTRODUCTION

Blockchains are increasingly used as platforms for applications called *smart contracts* [16], which automatically manage transactions in an unbiased, mutually agreed-upon way. Commonly proposed and implemented smart contracts include supply chain management [11], healthcare [10], *token contracts*, voting, crowdfunding, auctions, and more [9]. A *token contract* is a contract implementing a *token standard*, such as ERC-20 [1]. Smart contracts often manage *digital assets*, such as cryptocurrencies, or, depending on the application, bids in an auction, votes in an election, and so on. Token contracts are common on the Ethereum blockchain [17]—about 73% of high-activity contracts are token contracts [13]. Smart contracts cannot be patched after being deployed, even if a security vulnerability is discovered. Some estimates suggest that as many as 46% of smart contracts may have some vulnerability [12].

Psamathe (/səməθi/) is a new programming language we are designing around a new abstraction, a *flow*, representing an atomic transfer operation. Flows allow encoding semantic information about the flow of assets into the code. The Psamathe language will also provide features to mark types with *modifiers*, such as **asset**, which combine with flows to make some classes of bugs impossible.

Solidity is the most commonly-used smart contract language on the Ethereum blockchain [2], and does not provide analogous support for managing assets. Additionally, typical smart contracts

are more **concise** in Psamathe than in Solidity, because Psamathe handles common patterns and pitfalls automatically.

Other newly-proposed blockchain languages include Flint, Move, Nomos, Obsidian, and Scilla [6–8, 14, 15]. Scilla and Move are intermediate-level languages, whereas Psamathe is a high-level language. Obsidian, Move, Nomos, and Flint use linear or affine types to manage assets; Psamathe uses *type quantities*, which provide the benefits of *linear types*, but allow a more precise analysis of the flow of values in a program. None of these languages have flows or provide support for all the modifiers that Psamathe does.

2 LANGUAGE

A Psamathe program is made of *contracts*, each containing *fields*, *types*, and *functions*. Each contract instance in Psamathe represents a contract on the blockchain, and the fields provide persistent storage. Figure 2 shows a simple contract declaring a type, a field, and a transaction, which implements the core of ERC-20’s transfer function. ERC-20 is a standard for token contracts managing **fungible** tokens, and provides a bare-bones interface for this purpose.

Psamathe is built around the concept of a *flow*. Using the more declarative, *flow-based* approach provides the following advantages:

- **Precondition checking:** Psamathe automatically inserts dynamic checks of a flow’s validity; e.g., a flow of money would fail if there is not enough in the source, or if there is too much in the destination (e.g., due to overflow).
- **Data-flow tracking:** We hypothesize that flows provide a clearer way of specifying how resources flow in the code itself, which may be less apparent using other approaches, especially in complicated contracts. Additionally, developers must explicitly mark when assets are *consumed*, and only assets marked as **consumable** may be consumed.
- **Error messages:** When a flow fails, Psamathe provides automatic, descriptive error messages, such as

Cannot flow <amount> Token from account[<src>] to account[<dst>]:
source only has <balance> Token.

```
1 contract ERC20 {
2   mapping (address => uint256) balances;
3   function transfer(address dst, uint256 amount)
4     public returns (bool) {
5     require(amount <= balances[msg.sender]);
6     balances[msg.sender] =
7       balances[msg.sender].sub(amount);
8     balances[dst] = balances[dst].add(amount);
9     return true;
10  }
11 }
```

Figure 1: An implementation of ERC-20’s transfer function in Solidity from one of the reference implementations [5]. All preconditions are checked manually. Note that we must include the SafeMath library (not shown), which checks for underflow/overflow, to use the add and sub functions.

```
1 contract ERC20 {
2   type Token is fungible asset uint256
3   balances : any map one address => any Token
4   transaction transfer(dst : one address, amount : any uint256) {
5     balances[msg.sender] --[ amount ]-> balances[dst]
6   }
7 }
```

Figure 2: A Psamathe contract with a simple transfer function, which transfers amount tokens from the sender’s account to the destination account. It is implemented with a single flow, which automatically checks all the preconditions to ensure the transfer is valid.

Flows enable such messages by encoding all the necessary information into the program.

Each variable, field, and function parameter has a *type quantity*, approximating the number of values in the variable, which is one of: **empty**, **any**, **one**, **nonempty**, or **every**. Type quantities are inferred if omitted; every type quantity in Figure 2 can be inferred. Only **empty** asset variables may be dropped.

Modifiers can be used to place constraints on how values are managed: **asset**, **fungible**, **unique**, and **consumable**. An **asset** is a value that must not be reused or accidentally lost. A **fungible** value represents a quantity that can be **merged**, and it is **not unique**. For example, ERC-20 tokens are **fungible**. A **unique** value only exists in at most one variable, enforced by a dynamic check when the value is created; it must be an **asset** to ensure it is not duplicated. ERC-721 tokens are **unique**. A **consumable** value is an **asset** that it may be appropriate to dispose of, done via the **consume** construct, documenting that the disposal is intentional.

Psamathe has transactional semantics: a sequence of flows will either all succeed, or, if a single flow fails, the rest will fail as well. If a sequence of flows fails, the error propagates, like an exception, until it either: a) reaches the top level, and the entire transaction fails; or b) reaches a **catch**, and then only the changes made in the corresponding **try** block will be reverted, and the code in the **catch** block will be executed.

3 EXAMPLES

The complete Solidity and Psamathe code is in our repository [3].

```

1 contract Ballot {
2     struct Voter { uint weight; bool voted; uint vote; }
3     struct Proposal { bytes32 name; uint voteCount; }
4
5     address public chairperson;
6     mapping(address => Voter) public voters;
7     Proposal[] public proposals;
8
9     function giveRightToVote(address voter) public {
10        require(msg.sender == chairperson,
11            "Only chairperson can give right to vote.");
12        require(!voters[voter].voted,
13            "The voter already voted.");
14        voters[voter].weight = 1;
15    }
16    function vote(uint proposal) public {
17        Voter storage sender = voters[msg.sender];
18        require(sender.weight != 0, "No right to vote");
19        require(!sender.voted, "Already voted.");
20        sender.voted = true;
21        sender.vote = proposal;
22        proposals[proposal].voteCount += sender.weight;
23    }
24 }
```

Figure 3: A simple voting contract in Solidity.

3.1 ERC-20

Figure 1 shows a Solidity implementation of the ERC-20 function transfer (cf. Figure 2). Each ERC-20 contract manages the “bank accounts” for its own tokens, keeping track of how many tokens each user has; users are represented by addresses. This example shows the advantages of flows in precondition checking, data-flow tracking, and error messages. In this case, the sender’s balance must be at least as large as amount, and the destination’s balance must not overflow when it receives the tokens. Psamathe automatically inserts code checking these two conditions, ensuring that the checks are not forgotten.

3.2 Voting

One proposed use for blockchains is for voting [9]. Figures 3 and 4 show the core of an implementation of a voting contract in Solidity and Psamathe, respectively, based on the Solidity by Example tutorial [4]. Each contract instance has several proposals, and users must be given permission to vote by the chairperson, assigned in the constructor of the contract (not shown). Each user can vote exactly once for exactly one proposal, and the proposal with the most votes wins. Note that we can use values of type **address** to *select* values of type **Voter**, as done on line 13. We can do this because the *underlying type* of **Voter** is **address**; this feature allows referring to assets without the asset itself, which is a necessary part of writing such contracts.

This example shows Psamathe is suited for a range of applications. It also shows some uses of the **unique** modifier; in this contract, **unique** ensures that each user, represented by an address, can be given permission to vote at most once, while the use of **asset** ensures that votes are not lost or double-counted.

4 CONCLUSION AND FUTURE WORK

We have presented the Psamathe language for writing safer smart contracts. Psamathe uses the new flow abstraction, assets, and modifiers to provide safety guarantees for smart contracts. We showed two examples of smart contracts in both Solidity and Psamathe, showing that Psamathe is capable of expressing common smart contract functionality in a concise manner, while retaining key safety properties.

```

1 contract Ballot {
2     type Voter is unique asset address
3     type ProposalName is unique asset string
4
5     chairperson : address
6     voters : set Voter
7     proposals : map ProposalName => set Voter
8
9     transaction giveRightToVote(voter : address):
10        only when msg.sender = chairperson
11        new Voter(voter) --> voters
12    transaction vote(proposal : string):
13        voters --[ msg.sender ]-> proposals[proposal]
14 }
```

Figure 4: A simple voting contract in Psamathe.

In the future, we plan to implement the Psamathe language, and prove its safety properties. We also hope to study the benefits and costs of the language via case studies, performance evaluation, and the application of flows to other domains. Finally, we would also like to conduct a user study to evaluate the usability of the flow abstraction and the design of the language, and to compare it to Solidity, which we hypothesize will show that developers write contracts with fewer asset management errors in Psamathe than in Solidity.

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