Creating Interactive Visualizations of TopHat Programs

Mark Gerarts
Open University
Heerlen, The Netherlands
mark.gerarts@gmail.com

Nico Naus
Virginia Tech
Blacksburg, VA, United States
niconaus@vt.edu

Marc de Hoog
Open University
Heerlen, The Netherlands
mla.dehoog@studie.ou.nl

Tim Steenvoorden
Open University
Heerlen, The Netherlands
tim.steenvoorden@ou.nl

ABSTRACT

Many companies and institutions have automated their business process in workflow management software. The novel programming paradigm Task-Oriented Programming (TOP) provides an abstraction for such software. The largest framework based on TOP, iTasks, has been used to develop real-world software.

Workflow software often includes critical systems. In such cases it is important to reason over the software to ascertain its correctness. The lack of a formal iTasks semantics makes it unsuitable for formal reasoning. To this end TopHat has been developed as a TOP language with a formal semantics. However, TopHat lacks a graphical user interface (GUI), making it harder to develop practical TopHat systems.

In this paper we present TopHat UI. By combining an existing server framework and user interface framework, we have developed a fully functioning proof of concept implementation in Haskell, on top of TopHat’s semantics. We show that implementing a TOP framework is possible using a different host language than iTasks uses. None of TopHat’s formal properties have been compromised, since the UI framework is completely separate from TopHat. We run several example programs and evaluate their generated GUI. Having such a system improves the quality and verifiability of TOP software in general.

KEYWORDS

task oriented programming, user interface, functional programming

1 INTRODUCTION

Workflow software is present in most businesses and institutions nowadays. From health care and first responders, to commerce and industrial processes. Businesses use workflow software to streamline their processes, increase efficiency and reduce costs. In these sectors, reliability of software is crucial.

Previous research into workflow software in the functional programming community aimed to improve reliability, while at the same time reducing the effort of development. This led to the development of Task-Oriented Programming (TOP), a programming paradigm that aims to facilitate working with multiple people towards a shared goal over the internet. TOP separates the what from the how. This separation allows programmers to focus on the work that has to be done (what) instead of paying attention to design issues, implementation details, operating system limitations, and environment requirements (how) [1, 20].

iTasks [1], implemented in the functional programming language Clean [7], is the main TOP framework and has been around for a long time. iTasks has been used to create real-world applications, such as an incident coordination tool for the Dutch coast guard [14]. While this proves its practical usability, iTasks lacks in formalization. The iTasks semantics are given by its implementation, making it much harder to formally reason about iTasks programs. Previous attempts to mitigate this issue by some of iTasks' creators involved developing a separate iTasks semantics, which allowed them to perform model-based testing, but no formal verification [13]. Formal program verification is a very powerful tool to ensure the correctness of critical software, like the incident coordination tool. TopHat is a Domain-Specific Language (DSL) that paves the way to formally reason about task-oriented programs [26], by defining a formal TOP semantics. These semantics have been implemented in Haskell and Idris 1. Idris is a programming language that features dependent types and a totality checker, which is used to prove properties of TopHat programs.

Motivation

In this paper, we develop an interactive UI for TopHat. Before the development of TopHat, it was the case that iTasks, TOP and Clean were tied together very strongly. Previous research even suggests that certain specific Clean features are essential to the implementation of TOP [20]: uniqueness typing, data generic programming, dynamics [30] and a sophisticated backend using interpreted ABC bytecode on clients [18], to name a few. We want to show that none of those features are essential in implementing a TOP framework with a GUI. On top of that, we want to demonstrate that this can be achieved without making any changes to the TopHat language and its implementation in Haskell.

We expect this work to bring TOP to a bigger audience. The current Clean user base is quite small. Haskell is being used in production code, has a huge number of packages available online and an active community. Task-oriented programming could benefit from being ported to Haskell, making it available to a large community of both developers and researchers. Developing an interactive UI for TopHat brings this one step closer.

Motivated by the above, this paper presents a prototype framework written on top of TopHat’s Haskell implementation that is able to create interactive graphical user interfaces of TopHat programs.

1https://github.com/timjs/tophat-proofs
Structure
The remainder of this paper is structured as follows: we first provide some background about TOP, including iTasks and TopHat in Section 2. Section 3 introduces our TopHat UI prototype. Section 4 demonstrates the capabilities of our framework, including formal reasoning, using several example TopHat programs. We highlight related work in Section 5. Section 6 reflects on the goals and research questions outlined above. Section 7 concludes.

2 TASK-ORIENTED PROGRAMMING
This paper builds upon previous TOP research [1, 20, 26]. In this section we describe the basic idea of TOP and two TOP implementations: iTasks and TopHat.

2.1 Task-Oriented Programming
TOP is centered around the concept of tasks, which specify the work a user or system has to perform with a high level of abstraction. The smallest possible task represents the smallest amount of work a user or system can perform [20].

Combining small tasks allows creating large and complex applications using simple building blocks. Tasks can be combined using combinators: they can be executed sequentially, in parallel, or conditionally. These combinators closely resemble how collaboration happens in real life.

TOP aims to facilitate collaborating with multiple people towards a shared goal, over the internet. Creating complex applications is further facilitated because tasks are first-class citizens: they can be used as input of functions, they can be returned from them, and tasks can contain other tasks as value.

Tasks are interactive and input-driven. When a task receives input it is reevaluated and results in a new task. A task’s value can be observed at all times. Tasks can share information with each other, either directly through shared data stores, or by passing task values to continuations.

TOP itself focuses on the domain logic, with tasks providing merely a description of the work that has to be performed. It is left up to a TOP framework to do the heavy lifting, such as generating the user interface, storing and handling data, setting up a web server, and authenticating users. iTasks [19] is such a framework, implemented in the functional programming language Clean [7]. An example of a basic task in iTasks is presented in Listing 1. iTasks acts as the starting point for further research as well. Tonic [28] facilitates the subject for non-technical people by providing graphical blueprints of iTasks specifications. It also provides a way to monitor the process while end users are interacting with the application [27]. iTasks acted as the starting point for research into declarative user interfaces, first for SVG images [2] and later as a generalized solution [3].

2.2 iTasks
iTasks is a TOP framework that uses Clean [5] as its host language. It supplements Clean with a set of combinators, model types, and algorithms that allow the construction of task-oriented programs.

An example of a basic task was given in Listing 1. iTasks will automatically generate an entire application for this task. It uses generics to deduce that a task of type String requires a text input field. In Listing 2 we combine the task with a view task using a sequential step combinator. A user has to enter their name and is greeted by the program after stepping to the next task. Figure 1 shows how these steps would look in iTasks.

To summarize, TOP is made up of the following three core concepts:

- **Tasks** that describe the work that has to be performed, providing an abstraction that separates the what from the how [1].
- **Composition** of tasks through combinators, allowing the creation of arbitrarily large tasks.
- **Data** that is being passed between tasks sequentially and globally.

2.3 TopHat
TopHat is such a framework, implemented in the functional programming language Clean [7]. An example of a basic task in iTasks is presented in Listing 1. iTasks acts as the starting point for research into declarative user interfaces, first for SVG images [2] and later as a generalized solution [3].

Listing 2: Combining two tasks with a step combinator (Clean)

```haskell
greet :: Task String
  greet = enterName >>!
  \result -> viewInformation [] ("Hello " ++ result)
```

The TOP paradigm provides an abstraction over workflow software. Instead of having to write a server, database, user interfaces, etc., programmers just define what needs to be done. The complete application is then derived from this specification by the TOP framework. TOP is usually embedded in pure functional programming.
TopHat [26] distills TOP’s core features to provide a way to reason about task-oriented programs. By employing symbolic execution it is possible to formally verify TopHat programs [17]. Symbolic execution has also been used to provide end-users of tasks with additional feedback [16].

Our work is based on TopHat’s Haskell implementation. Listing 3 gives the TopHat implementation of the example introduced in Section 2.2. Similar to the iTasks code, this task uses a step combinator to ask a user their name and subsequently greet them.

![Listing 3: A TopHat task that greets the user (Haskell)](image)

TopHat contains the following set of tasks and combinators:

- **Editors** model user interaction. They are typed containers that are either empty or hold a value. TopHat contains different kinds of editors:
  - **Update** contains a predefined value.
  - **View** is an editor with a view-only value.
  - **Enter** is an editor that is initially empty. Filling it transforms it into an Update editor.
  - **Watch** displays the value of a shared data store.
  - **Change** is an editor that allows to change the value of a shared data store.
  - **Done and Fail** are success and failure end tasks.
  - **Pair** combines two tasks (parallel-and).
  - **Choose** makes a choice between two tasks (parallel-or).
  - **Step** sequentially moves from one task to another.
  - **Share** creates a shared data store.
  - **Assign** assigns a value to a reference in a shared data store.

### 2.4 Formal reasoning

iTasks defines tasks as a "state transforming function that reacts to an event, rewrites itself to a reduct and accumulates responses to users" [20]. For combinators, iTasks takes the swiss-army-knife-approach. It defines two combinators that perform a multitude of actions. From these combinators, more simple ones can be constructed. For example, the **·** combinator performs sequential composition, which TopHat has been developed in the first place. The prototype TOP UI framework presented in the coming section.

In this section we describe our prototype TOP UI framework, which is a proof-of-concept and not a fully fledged TOP framework. Our application supports TopHat tasks as mentioned in Section 2.3. We limit ourselves to a select number of datatypes: only integers, booleans, and strings are supported. Advanced framework features such as multi-user support are out of scope as well. We will reflect on this in Section 6. The framework is written in Haskell, and we use the following extensions.

- **OverloadedLists** to allow for a more convenient HashMap notation.
- **OverloadedStrings** to allow for a more convenient way of using Text.
- **PackageImport and NoImplicitPrelude** to deal with the fact that TopHat defines its own Prelude.

All source code is published on GitHub, along with the examples described below.

Key to our approach is that we leave the task specification of TopHat untouched. This preserves the nice formal properties for which TopHat has been developed in the first place. The prototype UI framework completely relies on the TopHat semantics for handling input and rewriting tasks. The responsibility of the UI

---

1. [https://github.com/clean-and-itasks/itasks-sdk/-/blob/master/Libraries/iTasks/WF/Combinators/Core.icl](https://github.com/clean-and-itasks/itasks-sdk/-/blob/master/Libraries/iTasks/WF/Combinators/Core.icl)

2. [https://github.com/mark-gerarts/ou-afstuderen-artefact](https://github.com/mark-gerarts/ou-afstuderen-artefact)
The prototype framework is architecturally separated in two parts: the backend and the frontend. Figure 2 shows the main modules of each part. The backend is responsible for initializing tasks and handling communication with TopHat. The frontend renders tasks and allows the user to interact with them. After a comparative study of existing web server and UI frameworks [11], we have selected Servant [21] as our webserver and Halogen [6] for the UI. Other options are discussed in the Section 5. Section 3.1 illustrates the communication between frontend and backend. Section 3.2 explains the working of the backend and the frontend is discussed in Section 3.3.

3.1 Communication between backend and frontend

Figure 3 shows the communication between frontend and backend. The frontend first requests the initial task, which the backend returns using a JSON representation of this task. A user can now interact with the system. In this example, the user updates a value. The frontend sends the input as JSON to the backend, and the backend responds with the updated task. This step can be repeated as necessary. In this case, the user resets the application, which results in the backend resetting back to the initial task.

The frontend is written in PureScript and the backend in Haskell. We choose JSON as data interchange format, because JSON allows custom data structures, it is easy to use, and both backend and frontend support JSON out-of-the-box.

3.2 Backend

The backend is written in Haskell, using Servant [21] as the web server. It has three main responsibilities, which is reflected in its module structure, shown in Figure 2:

(1) The Application module loads the application, defines the web server and configures the handlers.
(2) The Communication module handles JSON conversion, both encoding tasks to their JSON representation and decoding user input.
(3) The Visualize module is intended for the end user. It exposes functions to start the framework, which is demonstrated in Listing 5.

Listing 5: Starting the framework (Haskell)

```
import Task (Task, enter, view, (>>?>>))
import Visualize (visualizeTask)
main :: IO ()
main = visualizeTask greet

greet :: Task h String
greet = enter >>?>> \result -> view ('Hello ' ++ result)
```

Application module. We create an abstract web application (WAI-application) in the Application module (see the application function in Listing 6). We define the endpoints, the request and the response formats. For example, see the TaskAPI in Listing 6. The server function provides handlers to serve the initial task, to handle interaction with the frontend and to perform a reset. The remainder of the module consists of functions that expose functionality of TopHat: initializing tasks, deconstructing tasks in a representation that can be sent to the frontend, and interacting with tasks. We have only added key signatures to Listing 6.
module Application (application, State (..)) where

data State h t = State
  { currentTask :: TVar (Task RealWorld t),
    initialised :: Bool,
    originalTask :: Task RealWorld t }

type TaskAPI = "initial-task" :> Get '[JSON] TaskDescription
  <|> "interact" :> ReqBody '[JSON] JsonInput :> Post '[JSON] TaskDescription
  <|> "reset" :> Get '[JSON] TaskDescription

module Communication (JsonTask (..), TaskDescription (..), describe) where

type JsonTask = Value

type InputDescriptions = List (Input Abstract)

data TaskDescription where
  TaskDescription :: JsonTask -> InputDescriptions -> TaskDescription

instance ToJSON JsonTask
  describe :: Members ['[Haskell] RawHtml'] RawHtml

instance ToJSON Task
  describeIO :: Task h t -> IO TaskDescription

instance ToJSON TaskDescription
  describeIO :: Task h t -> IO TaskDescription

instance FromJSON JsonInput
  JsonInput :: Input Concrete -> JsonInput

instance FromJSON Task
  interactIO :: Input Concrete -> Task RealWorld a -> IO (Task RealWorld a)

instance FromJSON TaskDescription
  initialiseIO :: Task RealWorld a -> IO (Task RealWorld a)

instance FromJSON Task
  server :: ToJSON t => State h t -> ServerT API (AppM h t)

instance FromJSON TaskDescription
  application :: ToJSON t => State h t -> Application

Listing 6: Application module (Haskell)

Communication module. In Listing 7 we show the core of the communication module. We introduce a new datatype, TaskDescription, that holds all data we need to render a task: the task itself (JsonTask) and its possible inputs (InputDescription), along with the describe function that extracts this data from a TopHat task. User input, which is sent back and forth from the client to the server, is defined in JsonInput.

module Communication (JsonTask (..), TaskDescription (..), describe) where

data TaskDescription where
  TaskDescription :: JsonTask -> InputDescriptions -> TaskDescription

instance ToJSON JsonTask
  describe :: Members ['[Haskell] RawHtml'] RawHtml

instance ToJSON Task
  describeIO :: Task h t -> IO TaskDescription

instance ToJSON TaskDescription
  describeIO :: Task h t -> IO TaskDescription

instance FromJSON JsonInput
  JsonInput :: Input Concrete -> JsonInput

instance FromJSON Task
  interactIO :: Input Concrete -> Task RealWorld a -> IO (Task RealWorld a)

instance FromJSON TaskDescription
  initialiseIO :: Task RealWorld a -> IO (Task RealWorld a)

instance FromJSON Task
  server :: ToJSON t => State h t -> ServerT API (AppM h t)

instance FromJSON TaskDescription
  application :: ToJSON t => State h t -> Application

Listing 7: Communication module (Haskell)

Visualize module. In Listing 8 we show the signatures of the visualize module. We use this module to run the web server in production (visualizeTask) or development (visualizeTaskDevel) mode. We differentiate between these modes because we implemented live code reloading for development, which requires a bit of additional setup. Both visualizeTask and visualizeTaskDevel use the initApp function. InitApp on its turn invokes the application function of the Application Module.

module Visualize (visualizeTask, visualizeTaskDevel) where

initApp :: ToJSON t => Task RealWorld t -> IO Application

visualizeTaskDevel :: ToJSON t => Task RealWorld t -> IO ()

visualizeTask :: ToJSON t => Task RealWorld t -> IO ()

Listing 8: Visualize module (Haskell)

3.3 Frontend

The frontend renders the UI and provides a way for the user to interact with it. The code is written in PureScript using the Halogen framework. The frontend consists of three main modules and some auxiliary modules. We explain the main modules:

1. The Client module is the communication layer with the backend. It defines functions which send requests to the backend and handles the responses.
2. The Task module handles JSON encoding and decoding of our domain’s datatypes (tasks and user input).
3. The TaskLoader module is the starting point of Halogen and is responsible for rendering the UI.

Client module. The client module is responsible for the communication between frontend and backend. The backend sends a response in JSON that consists of two parts: a Task and a description of possible inputs. We decode this JSON object into a TaskResponse. See Listing 9.

module App.Client (ApiError, TaskResponse(..), getInitialTask, interact, reset) where

data TaskResponse where
  TaskResponse :: Task -> InputDescriptions

instance ToJSON TaskResponse
  getInitialTask :: Aff (Either ApiError TaskResponse)

instance ToJSON TaskResponse
  interact :: Input -> Aff (Either ApiError TaskResponse)

instance ToJSON TaskResponse
  reset :: Aff (Either ApiError TaskResponse)

Listing 9: Client module (PureScript)

Task module. In the Client module we defined a TaskResponse. This TaskResponse consists of two parts: a Task and an array of InputDescription. In the Task module we define the decoding process of Task and InputDescription. See Listing 10.


Listing 10: Task module (PureScript)

TaskLoader module. The TaskLoader module renders the user interface (the render function in Listing 11). The module also contains logic to handle events (handleAction), for example when a user modifies a value. Finally, the TaskLoader function (see Listing 11) initializes the component.

Listing 11: TaskLoader module (PureScript)

4 EXAMPLES

We present a few examples to demonstrate how our framework handles TopHat programs. The candy vending machine combines the Select and View editor, the Step Task, and the Pair Task to construct a candy machine (Section 4.1). The calorie calculator demonstrates a real-world application of our framework (Section 4.2). The chat sessions demonstrates the use of shared data stores (Section 4.3), and finally Section 4.4 describes UI generation for the tax example from Section 2.4

4.1 Candy vending machine

The candy machine allows a user to choose a chocolate bar and, after the bill is paid, the candy machine returns the bar. The candy machine combines the Edit, Pair and Step task. We have defined different Edit tasks with View and Select editors. The implementation of the initial task is given in Listing 12. The Pair combinator is denoted with the operator `<<`

(1) After the candy machine is started, the machine displays some introductory text and a selection of chocolate bars (see Figure 4a). This is done using a Pair Task that consists of two Edit tasks: an Edit task with a View editor and an Edit Task with a Select editor.

(2) Select a chocolate bar. After choosing a bar, the candy machine displays the price of the bar (see Figure 4b). This is done using another Pair Task that consists of an Edit task with a View editor (“you need to pay”) and a Step Task. The Step task consists of two tasks: first a view editor is shown (with the price) and after the step, a select editor is rendered (see Figure 4c).

(3) Press the continue button.

(4) Insert coins until you have paid the bill (see Figure 4c). The application alternates a view and a select editor.

(5) The application shows a view editor to indicate to the user that the bill is paid (see Figure 4d).

Listing 12: Initial Task of the candy vending machine (Haskell)

```haskell
data CandyMachineMood = Fair | Evil

startCandyMachine :: (Task h (Text, (Text, Text)))
startCandyMachine = view "We offer you three chocolate bars. Pure Chocolate: It’s all in the name, IO Chocolate: Chocolate with unpredictable side effects. " >> select candyOptions

where
  candyOptions = [ entry "Pure Chocolate" 8,
                   entry "IO Chocolate" 7,
                   entry "Sem Chocolate" 9
                ]

payCoin :: Int -> (Label, Task h Int)

payCandy :: Int -> Task h Text
payCandy bill = select (payCoin bill) >>? \billLeft ->
   case compare billLeft 0 of
     GT -> dispenseCandy Evil
     LT -> dispenseCandy Evil
     EQ -> dispenseCandy Evil

payCoin bill = [ coinSize 5, coinSize 2, coinSize 1 ]

where
  dispenseCandy :: CandyMachineMood -> Task h Text
  dispenseCandy Evil = view "You have paid too much! Sorry, no change, but here is your candy."
```

```haskell
module App.Task where

data Task
  = Edit Name Editor
  | Select Name Task Labels
  | Pair Task Task
  | Choose Task Task
  | Step Task
  | Done
  | Fail

instance showTask :: Show Task

instance decodeJsonTask :: DecodeJson Task

instance encodeInput :: EncodeJson Input

instance showInput :: Show Input

instance decodeJsonInputDescription :: DecodeJson InputDescription

instance showInputDescription :: Show InputDescription

module Component.Task where

startCandyMachine = view "We offer you three chocolate bars. Pure Chocolate: It’s all in the name, IO Chocolate: Chocolate with unpredictable side effects. " >> select candyOptions

where
  candyOptions = [ entry "Pure Chocolate" 8,
                   entry "IO Chocolate" 7,
                   entry "Sem Chocolate" 9
                ]

payCoin :: Int -> (Label, Task h Int)

payCandy :: Int -> Task h Text
payCandy bill = select (payCoin bill) >>? \billLeft ->
   case compare billLeft 0 of
     GT -> dispenseCandy Evil
     LT -> dispenseCandy Evil
     EQ -> dispenseCandy Evil

payCoin bill = [ coinSize 5, coinSize 2, coinSize 1 ]

where
  dispenseCandy :: CandyMachineMood -> Task h Text
  dispenseCandy Evil = view "You have paid too much! Sorry, no change, but here is your candy."
```

```haskell
module App.Task where

data Task
  = Edit Name Editor
  | Select Name Task Labels
  | Pair Task Task
  | Choose Task Task
  | Step Task
  | Done
  | Fail

instance showTask :: Show Task

instance decodeJsonTask :: DecodeJson Task

instance encodeInput :: EncodeJson Input

instance showInput :: Show Input

instance decodeJsonInputDescription :: DecodeJson InputDescription

instance showInputDescription :: Show InputDescription

module Component.Task where

startCandyMachine = view "We offer you three chocolate bars. Pure Chocolate: It’s all in the name, IO Chocolate: Chocolate with unpredictable side effects. " >> select candyOptions

where
  candyOptions = [ entry "Pure Chocolate" 8,
                   entry "IO Chocolate" 7,
                   entry "Sem Chocolate" 9
                ]

payCoin :: Int -> (Label, Task h Int)

payCandy :: Int -> Task h Text
payCandy bill = select (payCoin bill) >>? \billLeft ->
   case compare billLeft 0 of
     GT -> dispenseCandy Evil
     LT -> dispenseCandy Evil
     EQ -> dispenseCandy Evil

payCoin bill = [ coinSize 5, coinSize 2, coinSize 1 ]

where
  dispenseCandy :: CandyMachineMood -> Task h Text
  dispenseCandy Evil = view "You have paid too much! Sorry, no change, but here is your candy."
```
4.2 Calorie calculator

To demonstrate a more real-world application that incorporates most task types, we created a calorie calculator. This application calculates how many calories a person should eat per day in order to maintain their weight. The calculation depends on several factors, such as age, weight, and activity level. The application can be broken down in several steps to prompt the user for input, and finally calculating the result. The implementation of the task is given in Listing 13.

1. When started, the application presents the user with some information about the calculation using a View editor.
2. After pressing continue, the user is prompted to enter the required data in different steps: height, weight, and age using Enter editors, and gender and activity level using Select editors. Each prompt is wrapped in a Pair task with a View editor on the left side to act as the label. Such a prompt is shown in Figure 5.
3. In the last step the result is displayed using a View editor.

4.3 Chat session

This example uses shared data stores to model a chat session between two users, as displayed in Figure 6. Each user can write messages to the chat history on the left hand side using their respective inputs on the right hand side.

The implementation for this example is given in Listing 14. The function share creates a data store that can be accessed by multiple tasks, in this case the two chat tasks. The « operator is used to transform the contents of the shared data store.
4.4 Tax example

For our final example, we revisit the tax program from Section 2.4.

```haskell
tax :: Task h (((Amount, Bool), Bool), Date), Date)
tax =
  let today :: Date
      today = 100
      provideDocuments :: Task h (Amount, Date)
      provideDocuments = enter >>
        let invoiceAmount = 1000
        where
        invoiceDate = 88
      companyConfirm :: Task h Bool
      companyConfirm = enter
      officerApprove :: Date -> Date -> Bool -> Task h Bool
      officerApprove invoiceDate date confirmed =
        view (date - invoiceDate < 365 && confirmed)
        >>?
        
        invoiceAmount = 1000
        invoiceDate = 88
        confirmed = True
      in
        officerApprove invoiceDate date confirmed
        >>?
        
        let subsidyAmount =
        if approved
          then min 600 (invoiceAmount `div` 10)
        else 0
        in
        view
        "Subsidy amount: " ++ display subsidyAmount,
        "Approved: " ++ display approved,
        "Confirmed: " ++ display confirmed,
        "Invoice date: " ++ display invoiceDate,
        "Today: " ++ display today
```

Listing 15: Tax example in Haskell

Listing 15 gives the Haskell code that implements the task. Compared to the original definition as given in Listing 4, the task is nearly identical. The only change made is to the final line, where we have opted for a different presentation of the final result, for simplicity’s sake.

Figure 7 lists the different stages of the UI for the tax subsidy task. First, the user requesting the subsidy can enter information (first two tasks), while the company can confirm or deny. Then, the tax officer can verify if the conditions are met, and approve the request. Finally, the outcome is shown.

Since we did not have to modify the task at all, besides a minor presentation detail, this task can still be proven correct using symbolic execution. This example clearly illustrates the advantage of TopHat with a UI over the current state-of-the-art in the form of iTasks.

5 RELATED WORK

Section 2 presented related work on TOP and iTasks. In this section, we will briefly discuss Functional reactive programming as an alternative to TOP, as well as alternatives for the UI framework and web server we have used during the development of the UI for TopHat.

5.1 Functional Reactive Programming

Functional Reactive programming (FRP) is another approach to UI development using functional programming. FRP is a programming paradigm centered around interactive event-based applications. It has implementations in multiple programming languages, such as Haskell and JavaScript [4].

FRP consists of two main concepts: behaviors and events. A behavior consists of a value and can be mapped to output, for example a label. Behaviors can depend on other behaviors, so a change in a behavior can propagate through a network of dependent behaviors. An event only occurs at a certain point in time and contains a value. Input is mapped to events, for example the pressing of a key or the position of the mouse cursor. Events can trigger changes in behaviors.

It is worth noting that, while they share some similarities, FRP and TOP are conceptually different. FRP is a paradigm for reactive programming, whereas TOP is a way to model collaboration between users.
5.2 User Interface frameworks
We build upon the Halogen framework to create our prototype, but many other UI frameworks exist in the domain of functional programming. We discuss three of these briefly below.

Elm [9] refers to both Elm, a functional programming language that compiles to JavaScript [8], and TEA [10], a programming pattern that emerged from it. Elm’s ecosystem consists of a large number of available libraries that help in creating web applications. Miso [12] is a Haskell front-end framework inspired by Elm and Redux. It relies on GHCJS [15], a Haskell-to-JavaScript compiler based on GHC.

 Reflex [29] is an FRP framework written in Haskell with support for a variety of platforms, including the web, desktop, and mobile. Reflex applications are modular, which makes growing and refactoring an application efficient and swift.

We have selected PureScript and Halogen because it is a powerful functional programming language that fits our problem domain. Halogen provides an excellent developer experience, has a component-based architecture and builds upon PureScript’s power and expressiveness.

5.3 Web servers
We have opted for Servant as our web server. Servant provides combinators to implement our features, which makes coding less error prone and time-consuming. Servant is up-to-date, well-maintained, well documented and it is easy to get a working prototype. Below we discuss Yesod and Warp as possible alternatives for the server used in our implementation.

The Yesod Web Framework [23] is a Haskell web framework that allows for rapid development of type-safe, RESTful and high performance web applications [24]. The Yesod Web Framework adds the strengths of Haskell (like type safety) to the web. Especially on the boundaries of Yesod and the world, for example a user enters input or persistent data is loaded, Yesod adds mechanisms to define the expected types [22]. We found that developing a prototype based on Yesod is more difficult than developing a prototype based Servant. We also found that the Yesod Web Framework is too extensive for our purposes [11].

The Warp web server is a lightweight web server that supports the Web Application Interface (WAI) [25]. It is meant to be easy to use and provide easy composition of web services. Because of the design choices to achieve this, the code of a Warp prototype is low-level. This means that implementing all features in this way will be error prone and time-consuming. Therefore, we have chosen Servant. However, Servant also uses Warp as its web server [11].

6 CONCLUSION
We have demonstrated TopHat UI, a proof-of-concept framework that implements a GUI for Tophat programs. None of the advanced Clean features used by iTasks were required to do so, as expected. On top of that, we were able to leave the TopHat language untouched, preserving its formal properties.

Our framework implements all basic requirements for a TOP framework, by supporting tasks, shared data stores, combinators and generics. The source code for our framework is available online, and can thus be leveraged by developers and researchers to advance the field of Task-Oriented Programming.

6.1 Future work
As mentioned in Section 3, TOP features such as multi-user support and richer datatypes are considered future work. We see no technical or formal reason prohibiting them from being included in future versions of the UI framework. As with iTasks, the rendering of values, and editors of values, is generic in the type of the value. Adding support for more complex datatypes would just mean making instances for them for viewing and editing them, similar to how this is done in iTasks. As for multi-user support, this is a limitation in the current version of TopHat. Its developers are already working on adding multi-user support. Once this feature is released, we see no fundamental limitations in supporting this in the UI. The server framework used in the current implementation, Servant, already has extensive support for user authentication, which could be leveraged 4.

REFERENCES
[1] Peter Achten, Pieter Koopman, and Rinus Plasmeijer. 2015. An Introduction to Task Oriented Programming. Springer International Publishing, Cham, 187–245.
[2] Peter Achten, Jurrien Stutterheim, Lislòl Domoszlai, and Rinus Plasmeijer. 2014. Task Oriented Programming with Purely Compositional Interactive Scalable Vector Graphics. ACM, 1–13.
[3] Peter Achten, Jurrien Stutterheim, Bas Lijnse, and Rinus Plasmeijer. 2016. Towards the Layout of Things. ACM, 1–13. https://dl.acm.org/doi/10.1145/3064899.3064905
[4] Engineer Bainomugisha, Andoni Carretón, Tom Cutsem, Stijn Mostinckx, and Wolfgang Meuter. 2013. A survey on Reactive Programming. ACM computing surveys 45, 4 (2013), 1–34.
[5] TH Brus, Marko CJD van Eekelen, MO Van Leer, and Marinus J Plasmeijer. 1987. Clean—A Language for Functional Graph Rewriting. In Conference on Functional Programming Languages and Computer Architecture. Springer, 364–384.
[6] Burgess and Honeyman et al. 2021. Halogen. https://github.com/purescript-halogen/purescript-halogen. Version 6.1.2.
[7] Clean 2021. Clean. https://clean.cs.ru.nl. Version 3.0.
[8] Czaplicki. 2012. Elm. https://elm-lang.org. Version 0.19.1.
[9] Czaplicki. 2012. Elm Concurrent fsp for functional gui. Senior thesis, Harvard University (2012).
[10] Elm Guide 2021. The Elm Architecture. https://guide.elm-lang.org/architecture. Accessed at 2021-07-01.
[11] Mark Gerarts and Marc de Hoog. 2021. Creating Interactive Visualizations of TopHat Programs.
[12] Johnson. 2020. Miso. https://haskell-miso.org. Version 1.7.1.
[13] Pieter W. M. Koopman, Rinus Plasmeijer, and Peter Achten. 2008. An Executable and Testable Semantics for iTasks. In Implementation and Application of Functional Languages - 20th International Symposium, IFL 2008, Hatfield, UK, September 10-12, 2008. Revised Selected Papers. 212–232. https://doi.org/10.1007/978-3-642-24452-0_12
[14] Bas Lijnse, Jan Martin Jansen, Rinus Plasmeijer, et al. 2012. Incidente: A Task-Oriented Incident Coordination Tool. In Proceedings of the 9th International Conference on Information Systems for Crisis Response and Management, ISCRAM, Vol. 9.
[15] Mackenzie et al. 2021. GHCJS. https://github.com/ghcjs/ghcjs. Version 8.6.
[16] Nico Naus and Tim Steenvoorden. 2020. Generating Next Step Hints for Task Oriented Programs Using Symbolic Execution. In Trends in Functional Programming - 21st International Symposium, TFP 2020, Krakow, Poland, February 13-14, 2020. Revised Selected Papers, 47–68. https://doi.org/10.1007/978-3-030-57761-2_3
[17] Nico Naus, Tim Steenvoorden, and Markus Klinik. 2019. A symbolic execution semantics for TopHat. In IFL ’19: Implementation and Application of Functional Languages, Singapore, September 25-27, 2019. 1:1–1:11. https://doi.org/10.1145/3312932.3412933
[18] Arjan Oortgiese, John van Groningen, Peter Achten, and Rinus Plasmeijer. 2017. A Distributed Dynamic Architecture for Task Oriented Programming. ACM, 1–12. https://dl.acm.org/doi/10.1145/3205368.3205375

4https://docs.servant.dev/en/stable/tutorial/Authentication.html
[19] Rinus Plasmeijer, Peter Achten, and Pieter Koopman. 2007. iTasks: Executable Specifications of Interactive Work Flow Systems for the Web. ACM SIGPLAN Notices 42, 9 (2007), 141–152.

[20] Rinus Plasmeijer, Bas Lijnse, Steffen Michels, Peter Achten, and Pieter Koopman. 2012. Task-Oriented Programming in a Pure Functional Language. ACM, 195–206.

[21] Servant Contributors. 2021. Servant – A Type-Level Web DSL. https://docs.servant.dev/en/stable/index.html. Version 0.18.3.

[22] Snoyman. 2012. Developing Web Applications with Haskell and Yesod. O’Reilly Media, Inc.

[23] Snoyman. 2020. The Abominable Snoyman. https://www.snoyman.com/.

[24] Snoyman. 2020. Yesod Web Framework. https://www.yesodweb.com/.

[25] M. Snoyman. 2011. Warp: A Haskell Web Server. IEEE internet computing 15, 3 (2011), 81–85.

[26] Tim Steenvoorden, Nico Naus, and Markus Klinik. 2019. TopHat: A formal foundation for task-oriented programming. ACM, 1–13. https://dl.acm.org/doi/10.1145/3354166.3354182

[27] J. Stutterheim, P. Achten, R. Plasmeijer, V. Zsók, Z. Porkoláb, and Z. Horváth. 2019. Static and Dynamic Visualisations of Monadic Programs. Lecture notes in computer science (2019). 341–379

[28] Jurriaen Stutterheim, Rinus Plasmeijer, and Peter Achten. 2014. Tonic: An Infrastructure to Graphically Represent the Definition and Behaviour of Tasks. In International Symposium on Trends in Functional Programming. Springer, 122–141.

[29] Trinkle et al. 2020. Reflex. https://reflex-frp.org/. Version 0.8.0.0.

[30] Martijn Vervoort and Marinus J. Plasmeijer. 2002. Lazy Dynamic Input/Output in the Lazy Functional Language Clean. In Implementation of Functional Languages, 14th International Workshop, IFL 2002, Madrid, Spain, September 16-18, 2002, Revised Selected Papers. 101–117. https://doi.org/10.1007/3-540-44854-3_7