

**Figure 1: An illustration of how user input, written to a text file, is converted into a ROS node which publishes messages to a simulator or physical robot.**

For example, the following ROS Python client code will cause a mobile robot such as a Roomba or Turtlebot to follow a path that curves forward and left:

```

if __name__ == '__main__':
    pub = rospy.Publisher('turtle1/cmd_vel', Twist)
    rospy.init_node('publisher_node')
    loop_rate = rospy.Rate(5)
    while not rospy.is_shutdown():

```

while the equivalent code in *Improv* is

```
turtle1 $ forward || left
```

where `||` is an operator which combines movements in parallel.

# Improv: Live Coding for Robot Motion Design

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## ABSTRACT

This paper introduces the Improv system, a programming language for high-level description of robot motion with immediate visualization of the resulting motion on a physical or simulated robot. The intended users of this tool are anyone looking to quickly generate robot motion, such as educators, artists, and researchers. The system includes a domain-specific language, inspired by choreographic techniques, which allows for several ways of composing and transforming movements in space and time. Instructions in the Improv programming language are then executed with *roshask*, a Haskell client for ROS ("Robot Operating System"). ROS is an open-source robot software framework which is widely used in academia and industry, and integrated with many commercially available robots. However, the ROS interface can be difficult to learn, especially for people without technical training.

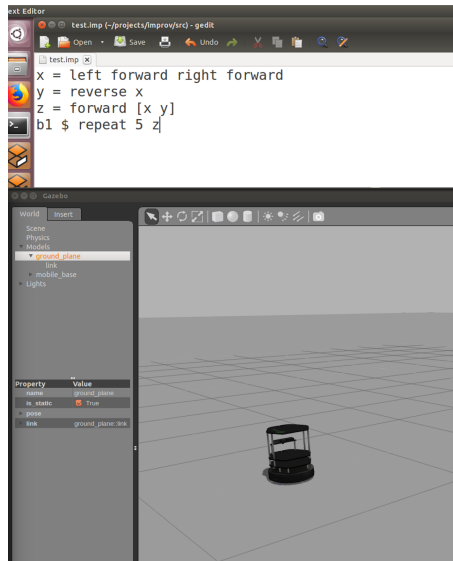
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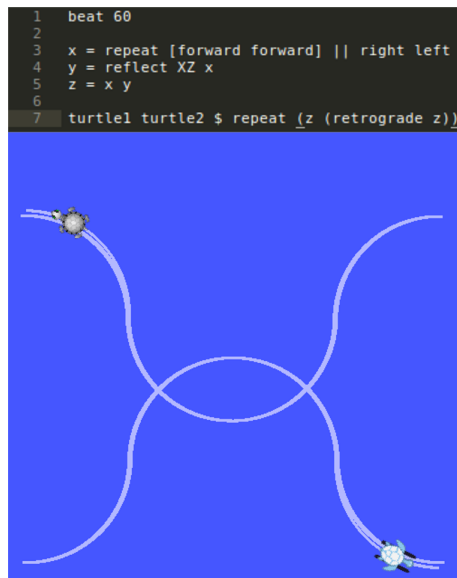
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(a) A program as it appears in Gedit, a simple graphical text editor, with the physics-based simulator Gazebo and a simulated Turtlebot.



(b) A program as it appears in vim, a terminal-based text editor, with the resulting movement in TurtleSim on two simulated turtles.

This paper presents a "live coding" interface for ROS compatible with any text editor. Currently, Improv can be used to control any robot compatible with the 'Twist' ROS message type (which sets linear and rotational velocity). This paper presents Improv implementations with the two-dimensional simulator Turtlesim, as well as three-dimensional TurtleBots in the Gazebo simulation engine.

## KEYWORDS

robotics, choreography, live coding, ROS, Haskell, roshask, HRI

## INTRODUCTION

Robotic technology is becoming more commonly integrated into settings outside of the factory - including classrooms [14] and art installations [22]. There is also an increasing need for robotic technology in research labs and workplaces for automating repetitive or uncomfortable tasks, in which case users often only need to specify a few simple movements. All of these applications would benefit from a method of programming robots that is faster and more high-level than the current workflow.

Currently, many commercially available robots are programmed through proprietary interfaces (which may be graphical, text-based, or physically interactive) or through ROS (the "Robot Operating System," a middleware and collection of libraries which manages message passing between the many components of robot systems) [20] [19]. However, this workflow has two obstacles that often make robot programming difficult, especially for newcomers to the field. First, the programming languages and interfaces are often at a low level of abstraction, forcing users to translate their mental model of their intended movement, often introducing mistakes and frustration. Second, the process of writing code, compiling and executing the instructions on the robot platform can be time-intensive and requires the user to switch between several different software modalities (text editor, to command line, to simulation software or hardware platform).

The tool introduced in this paper, *Improv*, addresses both of these problems. To address the first (mismatch between the problem and program domains), we introduce a small domain-specific programming language (DSL) with motion primitives and several operators which allow movements to be combined and transformed, in space and time. The transformations are inspired by choreographic techniques, such as those in [13] [7] [2] and [12].

To address the second obstacle to robot programming (the difficult process of evaluating code on a robot), we introduce a "live coding" infrastructure: when changes to the program file are saved, the process of interpreting code and converting high-level commands to low-level ROS messages is done automatically and the user can observe the effects on the simulated or physical robot nearly immediately.

By addressing these two shortcomings of current robot programming tools, we hope to make robotics more accessible and usable for a broader range of people, not just expert roboticists. Possible users of this tool include artists, educators, newcomers to robotics, and anyone who wishes to quickly prototype robot motion patterns. *Improv* is open-source and available at *[redacted]*. Please let us know if you try it out!

*Related Work.* We are aware of two other projects addressing the problem of the complex development cycle in ROS by creating tools for interactive or “live” programming. One such project [1] created a DSL in Python which allows for wrapping and modifying existing ROS nodes, using the Python shell. However, by using the Python shell, the user is only able to experiment with commands in a shell and is not able to save the commands they have tried in a file. Additionally, since the DSL is implemented as a library in Python, it inherits some of the opaque syntax of the Python ROS client. *Improv* has a simpler, albeit less powerful, programming language and models movement explicitly. Another closely related work to *Improv* is the Live Robot Programming (LRP) language [4] and its integration with PhaROS [8], a client library for ROS written in Pharo, a dynamic programming language specialized for live updating and hot recompilation. This project allows for live coding of ROS nodes and reconfiguration of the ROS network with a much shorter development cycle than traditional ROS programming. However, the aims of these projects and *Improv* are different - the LRP DSL, while more high-level than most robot programming languages, was not designed around modelling movement itself and instead models state machines that transition on events. Both of these related projects are better suited for applications which involve reactivity and sensing of the environment, while *Improv* is better suited to applications where the user wishes to quickly generate certain movements and creatively explore movement patterns.

This work is also heavily influenced by live coding interfaces and programming languages for generating music and visuals, which are often associated with the Algorave performance movement [5]. In particular, the programming language TidalCycles [16] has had a strong influence on this work, both syntactically and in how relative timing of events is managed. *Al Jazari* is a live coding installation which uses a simple graphical language to allow people to control robots (in simulation) [15]. The language includes conditionals based on external state and communication between the bots. The program state of the robot is also visualized. There are a variety of other projects centered around live coding interfaces for controlling cyberphysical systems and visual simulators, such as Extempore and integrations of TidalCycles with Unity3D [3]. These initiatives are often more purely focused on performance than *Improv*, and as far as we know, none are compatible with ROS.

In the robotics space, another closely related project to *Improv* is *Dance*, a domain-specific language built in Haskell [11]. The project includes a DSL inspired by Labanotation, as well as a reactive layer that allows the robot to respond to sensor events. The project targets humanoid robots, while *Improv*

has so far targeted mobile robots, and *Dance* would generate the necessary 3D simulation code, though did not include the live coding interface of this work and predates ROS. *Improv* has incorporated and adapted some of the data structures from *Dance*, namely the Action and Dance data types. Another relevant project is *roshask* [6], a Haskell client library for ROS, which this project uses as an interface between our domain-specific language and ROS. Some relevant design features of *roshask* will be described in Section . Especially when used with the two-dimensional Turtlesim, *Improv* is reminiscent of *Logo* [18], an educational, interpreted dialect of Lisp that is often used in conjunction with a simulation of a two-dimensional turtle. Our programming language is less expressive and powerful than *Logo*, but is integrated with ROS and thus able to be used with three-dimensional simulators and actual robots.

*Paper Outline.* Section details how this work was inspired by embodied improvisation for robot motion design, as well as concepts from the field of human-computer interaction, and the resulting design principles for the tool. Section provides an overview of the software architecture, how the features of *Improv* implement our design principles, and some example programs. Section describes some of the design decisions and features of the high-level domain-specific language, as well as the corresponding design choices in the Haskell backend. Section details more about how ROS messages are defined for specific robotic platforms, and how the live coding interface is implemented. Finally, Section summarizes our conclusions and outlines directions for future work, including user studies.

## PROTOTYPING MOVEMENT DESIGN IN EMBODIED IMPROVISATION

*Improv* is a tool for *prototyping* robot motion. Put another way, it is a tool for improvising movement on robot platforms. The authors have taken inspiration from their experiences with embodied improvisation, which is often used by choreographers and dancers as a way of understanding and creating human movement. Experts such as William Forsythe have analyzed strategies for improvisation for choreography and performance [9]. Improvisation helps the movement designer understand and explore the plethora of movement options that are available at any given time. This is especially useful in robotics applications as the field starts to explore stylized movement and the incorporation of robotic technology into homes and artistic performances. For example, one may explore different ways of picking up a cup (as if one is underwater, or as if one is being electrocuted, or in the style suggested by different pieces of music) in order to understand how many different ways there are for a robot to perform one task, and the perceived effects of all these different motion strategies.

However, the time taken to set up environments and write, compile and execute code often negates the benefits of improvisational practice when done on a robotic platform instead of a human body. This is doubly true when working with robotic hardware, and these barriers especially affect those

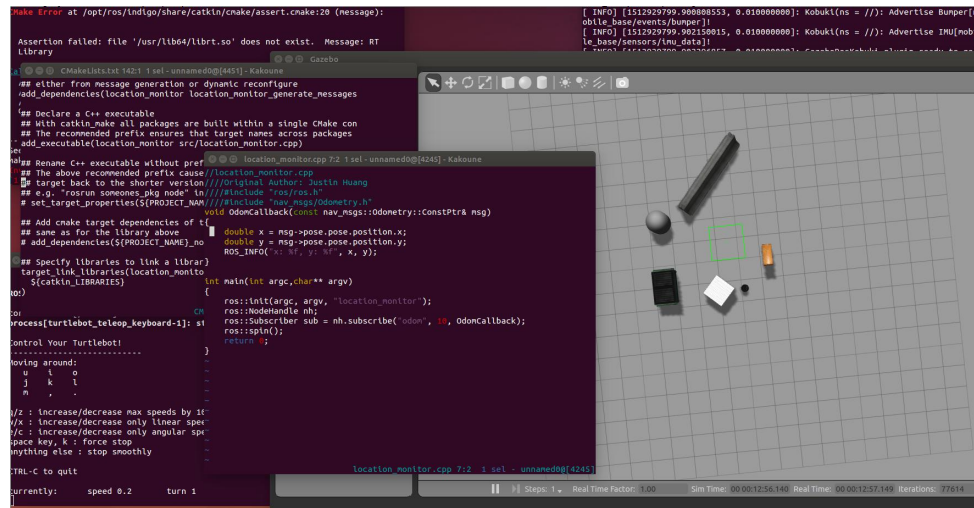


Figure 3: An example of a typical workflow in ROS, created by following a beginner tutorial. There are five overlapping terminal windows open, as well as the Gazebo simulator.

users who do not have a strong background in programming. This places some design constraints on the *Improv* system - namely, the system must have

- a minimal “representational distance” between the user’s mental model of the movement they want to try and the description in code, so there is minimal frustration and time wasted in translation,
- a near-imperceptible delay between writing instructions to the robot and seeing the effect of those instructions, and
- a singular environment where the user interacts with the program (to avoid the user’s attentional flow being broken by needing to switch between different interaction modalities).

These and similar design principles have been thoroughly studied in the field of human-computer interaction. In particular, the authors were inspired by several of the principles outlined in the ‘cognitive dimensions of notations’ [10]. There are eleven ‘cognitive dimensions,’ or design principles, that the authors describe but several are especially relevant to this work, such as

- *Closeness of mapping*: What ‘programming games’ need to be learned?
- *Diffuseness*: How many symbols or graphic entities are required to express a meaning?

- *Error-proneness*: Does the design of the notation induce ‘careless mistakes’?
- *Hard mental operations*: Are there places where the user needs to resort to fingers or pencilled annotation to keep track of what’s happening?
- *Progressive evaluation*: Can a partially-complete program be executed to obtain feedback on ‘How am I doing’?

Designing *Improv* with these principles in mind has helped us minimize the mental load of using the tool, and enable faster prototyping and a more improvisational workflow.

### IMPROV ARCHITECTURE AND FEATURES

See Figure 1 for a diagrammatic representation of the components in the *Improv* system and their relationships.

Several design features have been chosen to address the design constraints in Section (rapid development cycle, more natural translation of movement to code, and a single user environment). These design choices were made in part due to the usual workflow in ROS. For example, a beginner tutorial for ROS will have the user open at least three terminal windows (one for starting the ROS server, one for starting a publishing node, and one for starting a subscriber or simulator) and an editor, for a total of five windows (including the simulator). This process can be very intimidating for people who may not have experience with Linux or the command line, and the multitude of windows and interaction modalities make it difficult for the user to have a coherent mental model of information flow in the system. It is often not possible to see all the relevant windows at one time on a regular computer monitor. See Figure 3 for an example.

Despite its lack of user amenities, ROS is a very powerful tool - it is integrated with many commercially available robot platforms, and includes many libraries for standard robot use cases. Thus, we have chosen to design *Improv* as a wrapper around ROS. This gives us the benefits of ROS’s infrastructure, but we exchange the powerful low-level control available in most ROS client libraries for the simplicity of a high-level representation of robot motion. To specifically address the design criteria in Section , we have included the following features in *Improv*:

- *small representational distance between movement and code*: a domain-specific language, inspired by choreographic techniques such as spatial symmetries, relative timing changes, and body-centric coordinates. Many domain-specific languages for robot programming exist; for example, a review in 2016 identified 137 relevant publications [17]. However, most model robotic systems from a control-flow perspective, and do not model motion directly. The desired language will depend heavily on the programmer’s task, but undoubtedly there are many applications where users would like to describe the robot’s instructions directly in terms of movement. It then

makes sense to directly use the expertise and terminology developed by choreographers and other movement experts.

- *rapid movement prototyping*: changes to the user's file are interpreted by a Haskell program that builds a ROS node for publishing messages to a simulator or physical robot. This process is nearly real time, allowing for a seamless user experience.
- *workspace with few attentional switches*: a live coding interface with only two windows, one for editing the text file and one for observing effects on a simulated robot. Currently, we have tested the system with:
  - TurtleSim: a two dimensional simulator where velocity commands nearly perfectly control an animated turtle.
  - Gazebo with a TurtleBot robot model: a three-dimensional simulator with more realistic physics, where velocity commands control simulated motors.

The first feature, the domain-specific language, corresponds to the cognitive dimension *closeness of mapping*. As Green and Petre described, "the closer the programming world is to the problem world, the easier the problem-solving ought to be. Ideally, the problem entities in the user's task domain could be mapped directly onto task-specific program entities, and operations on those problem entities would likewise be mapped directly onto program operations" [10]. This also helps along the dimension of *diffuseness*: as the example in the introduction showed, we are able to express a movement such as curving forward and left very concisely, without cluttering the code space with the low-level infrastructure requirements of most ROS client libraries. Less noisy code also helps with *error-proneness*, since the user does not need to manually configure as many settings. We have also tried to make our parser flexible, by allowing different amounts of whitespace between lines and operators, though this area could certainly use more improvement. The final two features, the fast compile time and simple user environment, both help reduce *hard mental operations* and gives the user a fast and easy way to use *progressive evaluation*.

All of these features are intended to give the user a sense of *flow*: a mental state of complete absorption in the activity. The fewer distractions and focus changes in the activity, whether it is improvisational dance or coding, the higher the chance of the participant becoming completely engaged and accessing all the creative options available.

As examples of possible user interfaces, Figures 2a and 2b show examples of the system in use with two different text editors and two different simulators. Note that the choice of editor and the choice of simulator are decoupled, and *Improv* is absolutely editor-agnostic, relying only on an operating-system level script to execute changes. *Improv* is somewhat simulator-agnostic: currently it is only possible to control robots which use a Twist ROS messages for control, which set desired linear and rotational velocities.

```

prim → rest
      | forward
      | left
      | halfleft
      | right
      | halfright

movement → prim
          | movement movement
          | [movement]
          | (movement)
          | movement || movement
          | transformer movement

transformer → reverse
            | retrograde
            | repeat n
            | reflect ax

```

## DOMAIN SPECIFIC LANGUAGE (DSL) DESIGN

The base type of the *Improv* language is a movement. Movements are discretized and can be combined with each other in various ways, forming new movements, which can be in turn transformed and combined. The precise way in which this is interpreted on a robot platform is defined by the language's translation to Haskell and the resulting messages sent over the ROS network, which will be described further in Section .

Figure 1 shows the grammar of the *Improv* language. The language supports primitives such as forward and right corresponding to commands to the robot causing it to perform the expected motion. These primitives are composed in series, sequence and parallel, and transformed in time and space.

Movements are organized in time into units, where each unit is performed in one “beat.” The base timing of beats (units per minute) can be specified by the user, and is only limited by the maximum publishing frequency of ROS and the physical constraints of the robot platform.

Users can specify a series of commands such as *move forward for one beat, turn right for one beat, move forward for one beat* with the command `forward right forward`. Movements separated by whitespace on the same line will occur in different “beats.”

The user can also use brackets to compress a sequence of movements into one beat, such as `[forward right forward]`, which will cause these three movements to happen in the same amount of time as the first movement in the previous example. This syntax and behavior is directly inspired by *TidalCycles*, which has a similar mechanism for grouping sounds. In our implementation, bracketing  $n$  movements causes each movement to be performed  $n$  times faster, but for  $1/n$  times as long, so the movement has the same spatial extent but is performed faster.

Movements can also be performed in parallel, such as `forward || right`, which will cause the robot to curve to the right as it moves forward. In our implementation, velocities in parallel are simply added, so `left || right` would result in no movement. Movements in parallel will terminate when the “shorter” movement ends, so the program `(forward right) || forward` will never turn right (parenthesis are used to group movements without changing timing).

We have also implemented several transformations which map a function over a movement. For example, `repeat` takes an integer and a movement as arguments and causes that movement to repeat for the specified number of times.

In space, we have `reflect`, which takes a plane and a movement as arguments and returns the reflected movement (`reflect YZ right` yields `left`, where the YZ plane is body-centered and could also be called the sagittal plane). For transforming movements in time, `reverse` is a unary operator which will reverse the order of a series of movements: `reverse (forward right left)` is equivalent to `left right forward`. To reverse the trajectory itself, we use `retrograde`, which uses spatial



reflections and reverses time; for example, retrograde (forward right left) is equivalent to right left backward. Both retrograde and reverse are their own inverses: applying them twice returns the original movement, as would be expected.

While we have only implemented these combinators for simple and very symmetric mobile robots, one could imagine making more complicated types of symmetry for other robot platforms. We have included a typeclass `Symmetric a`, parameterized by a body type `a`, and defined by a function `refl :: Plane -> a -> a`. By defining this typeclass once for a new robot platform, detailing all the different symmetries of the body, the functionality of these spatial transformers can be extended to new platforms.

### Multiple Robots

The *Improv* system has the capability to control multiple robots at once, using a syntax which mirrors how *TidalCycles* allows for multiple tracks to be played simultaneously. Each robot is given a unique name in the shell script which launches ROS and the *Improv* system (this is also where the initial location of each robot is specified). Then, in the user's program, they specify which movement sequence should be associated with each robot. For example, to make robot `r1` move forward and robot `r2` move backward, the user would write

```
r1 $ forward
r2 $ backward
```

This syntax, along with assigning movements to variables, can make it easy to specify relationships between how different robots are moving, such as

```
x = left right [forward right]
r1 $ x
r2 $ retrograde x
```

which would cause robot `r2` to perform the same movement as robot `r1`, but in retrograde. It is also possible to command two robots to do the same movement with a program such as

```
r1 r2 $ forward backward
```

As *Improv* is extended to other platforms in the future, this could be an interesting mechanism for studying how the same high-level choreographic commands are perceived when executed on different platforms.

### Modelling Movement in Haskell

Programs in the *Improv* DSL are interpreted by a compiled Haskell program into an abstract data type (ADT), which represents each movement. This ADT, which we call a *Dance*, can be thought of as a tree that holds all movement primitives and their compositions and transformations. To execute a

Dance as a series of ROS messages, we must flatten the tree while maintaining their relative timing information, which will be discussed in Section .

Dances are defined as

```
data Dance b = Prim Action Mult b
              | Rest Mult
              | Skip
              | Dance b :+: Dance b
              | Dance b :||: Dance b
```

where *Prim* is a motion primitive type, composed of the *Action* (direction and spatial extent of the movement), *Mult* which stores timing information, and *b*, a parameterized type describing the part of the robot to move. *Rest* indicates that the robot part is not moving for some period of time (and is a primitive in the *Improv* language).

*Skip* is the identity dance, having no effect on the robot for no time duration, and is necessary for the monoidal structure of the parallel and series operators (*:||:* and *:+:*, respectively), which are binary operators on Dances.

This algebraic structure helps enforce the timing behavior that we expect; namely, associativity. If *d1*, *d2*, and *d3* are all Dances (with an arbitrary number and structure of movement primitives in each), then we want to ensure the following equivalence:

$$(d1 :+: d2) :+: d3 = d1 :+: (d2 :+: d3).$$

Similarly, if three Dances are in parallel, arbitrary groupings should not change the meaning of the program. This is exactly the behavior that the algebraic objects *monoids* have: associativity and an identity element. See [23] for a much more detailed discussion on the usefulness of monoids in modelling and programming languages, in the context of *Diagrams*, a Haskell DSL for creating vector graphics.

We create monoid instances in Haskell for these operators on Dance data types, which allow for lists of Dances to be combined in sequence or parallel. This is useful because the parser returns expressions in the user's program as a list of Dances. By implementing our intuitive understanding that movements in parallel and series should be associative as an algebraic structure, we can use the power of Haskell's abstractions to get the correct behavior "for free."

Similarly, we use the Haskell functionality for mapping functions over data structures (such as our Dance trees) to implement transformers such as retrograde and reverse. We define these functions recursively over the Dance ADT, by first defining a function *transform* which has two arguments: the first, a function transforming individual Actions (for example, flipping them over a spatial axis, or shrinking their extent), and the second being a Dance. The *transform* function then returns the

transformed Dance. This allows us to abstract out transformations from the low-level details of how they are propagated through the ADT, making it easier to implement new transformers.

### Relative Timing

As programs are parsed and converted to ROS messages, we must enforce the timing semantics - for example, movements inside square brackets, such as `[forward right forward]`, must occur within one “beat.” The parser returns such a program as a list of Dances, labelled with a type that indicates that they should be compressed in sequence. Then we call a function `seqL` which uses the length of the list to determine how much to speed up each individual dance before composing the movements. This is accomplished with a function `changeTiming` which takes a multiplier `m` and a Dance, and propagates the multiplier through the Dance recursively. This allows for nested sequential movements: for example, the program `[forward [left left] forward]` would result in timing multipliers `[3, 6, 6, 3]`. Note that the `left` primitives will have Mults of 6, since they must occur six times as fast as normal to allow the whole movement to occur in one “beat.” Thus, movements are able to be arbitrarily sped up by placing them in sequence inside square brackets. Movements can only be slowed down by decreasing the beat parameter in the program file, which sets the number of time units per minute. By making this number smaller, movements such as a quarter turn will be slowed down to fill the specified unit of time. Future work may include a language primitive which is able to do this for smaller chunks of code inside the program file, instead of needing to change the global timing parameter.

### INTERFACING WITH ROS

*Roshask* is a client library for ROS, written in Haskell. It treats streams of values (such as those published and subscribed to by ROS nodes) as first class values, which allows for them to be combined and transformed in more natural ways than imperative ROS client libraries. For example, when we put Dances in parallel, we wish to combine two lists of motion commands with some function for parallel execution - whether this is averaging commands which affect the same body part, or additively combining them, or whatever interpretation the designer wishes for a specific robot platform. In Haskell, this is accomplished easily with the `zipWith` function, which takes two lists and a function for combining values in those lists. *Roshask* extends this expressivity to the combination and transformation of ROS message streams, making it a useful tool for implementing the *Improv* DSL.

The primitives in *Improv*, such as `forward` or `right`, are mapped to streams of ROS messages. In our implementation so far, we have mapped to the Twist ROS message, which specifies the robot’s linear and angular velocity as two three-dimensional vectors. Velocity controllers, which often are

included with commercial robots, are required to create the low-level motor controls for reaching and maintaining the desired velocities.

To integrate a robot with *Improv*, one must specify how to convert the Dance data structure to a list of ROS messages. For example, for a non-articulated symmetric mobile robot (such as a Roomba or TurtleBot), this is accomplished by two functions: `moveBase` and `danceToMsg`. Since the robot has only one body part, `moveBase` takes an Action (direction and extent of movement) and converts it to a single ROS velocity command (which sets the desired linear and rotational velocity in the plane). Here, we have simplified the language by varying only three velocity values, the robot's  $x$ ,  $y$ -velocity in the plane and its angular velocity in the plane.

Since our discretization of movements is relational (for example, you can have Full, Half, and Quarter extent, and directions are related through symmetries), only a small number of these translations from Actions to velocities need to be explicitly defined and the rest can be derived through their relations. For example, `moveBase (A dir Half)` is defined as `fmap (*2) (moveBase (A dir Quarter))`, where `fmap` maps the function `*2` over the values in the velocity command returned by `moveBase (A dir Quarter)`. This encodes the relationship that a Half extent is twice as far as a Quarter, thus the robot must move twice as fast in the same direction to travel twice the distance in the same amount of time. Defining these relationships explicitly helps speed up recalibration or extension of the platform to new robots and simulators - onwith mappings from Dances to ROS messages need to be hard coded, and the rest are derived from the relations.

Once this conversion (from a Dance data structure to a list of ROS messages) has been completed, the list of ROS messages is passed to a ROS node defined in *roshask*. This node publishes the commands over the ROS network. Even if multiple robots are controlled, the system still only uses one ROS node which publishes to multiple topics. Work is ongoing on whether to extend the system to control multiple ROS nodes, and if so, how best to implement this feature.

### Live Coding Interface

One important design decision for developers of interactive text-based programming tools is whether to tie their tool to a specific editor. For example, the live coding tool TidalCycles was originally developed for Emacs, a powerful editor which has a notoriously steep learning curve. Many people prefer to use simpler editors, so new live coding plug-ins have been developed for editors such as Atom and Sublime Text. This editor-based approach has advantages, such as a large degree of customizability and extensibility using the features of the editor. However, it also introduces challenges such as maintaining feature parity between editors, as well as the up-front investment needed to interface with new editors. In our case, we are developing a tool that should be usable by artists, children, and programming novices, as well as experienced roboticists. Thus, we wish to allow users flexibility to choose their editor of preference.

To accomplish this, instead of creating an interface for each desired editor, we use a shell script which monitors the file that the user is editing for changes. Every time the user saves changes to the file, the program detects a change, interprets the user's new program, and resets the simulator and ROS node. This design choice circumvents the need to interface with specific editors. Additionally, many editors have keyboard shortcuts for saving files. Thus, executing programs contributes minimally to the overall workload of using the system, especially when compared to the many steps required to test changes to traditional ROS programs. The delay between saving the file and observing the changes in the simulator is very short - while we have not done a formal timing analysis, the delay is a small fraction of a second and not noticeably longer than the time it takes to look from the text editor to the simulator.

## CONCLUSIONS AND FUTURE WORK

This paper has presented a working implementation of a domain-specific language which is interpreted and executed as a stream of ROS messages published by a ROS node. Due to fast and automated interpretation of user programs, this system allows for a very tight feedback loop while programming robots. We hope that this feature, along with a programming language which models movement directly instead of the abstract state control flow typical of robotics languages, will decrease the cognitive load associated with robot programming. We aim to make the creative development of robot motion patterns faster, easier, and more accessible to a broader swath of potential users.

To this end, future work will include systematic studies of people's qualitative assessment of the usability of the system, as well as quantitative measures on how quickly people iterate on programs in the *Improv* language and how much the robot moves as a result. As far as we know, no similar usability studies have been performed on the more mainstream C++ and Python ROS clients. We plan to include a range of participants in our study, including people with limited programming experience and no ROS experience, as well as people familiar with ROS. From our own explorations of the tool, we have found that the experience is quite engaging, especially when using the three-dimensional physical simulator. We have included a video as supplemental information of *Improv* being used with Gazebo. We are very interested in measuring the effects of different editing and simulating environments on the user experience.

The main limitation of *Improv*, as compared to other live coding tools for ROS, is that it includes no features for controlling the robots based on sensor observations or interactions with the environment. An interesting future extension of this work would be to interface the *Improv* DSL with ROS subscribers and include conditional instructions which depend on sensor readings and environment state.

Another limitation of *Improv* is the complexity of extending the DSL and ROS interface to new robot platforms. This process requires defining the conversion from Dance data structures to ROS messages in Haskell, and may be especially tricky for robots with many body parts and degrees of freedom.

Additionally, we have only implemented the system for robots which have velocity controllers, and several aspects of the movement transformation model depend on this assumption. Future work will involve extending the language and interface to more complicated robots and refactoring the code base as necessary to make this extension process more accessible.

<sup>1</sup><https://github.com/ros2/ros2/wiki>

Many features and limitations of ROS are being improved with the ROS2 project<sup>1</sup>, especially cross-platform functionality, ease of creating client libraries, and more robust network middleware libraries. However, as far as we are aware, there is no Haskell client library for ROS2. As the ROS2 project is developed, the *Improv* project could be adapted to the new framework to increase its robustness and cross-platform functionality.

Finally, we would like to emphasize that the design decisions for how *Improv* programs are realized on robot platforms are relatively arbitrary and a single robot could have a multitude of different implementations. As Thecla Schiphorst has written, “it is not technological constraints that hold us back from using technology in new ways; technology changes at a tremendous rate. Our willingness to explore beyond the constraints of our imagination has the greatest effect” [21]. We hope that the implementation described here opens up new avenues of imagination for how robot programming can become better, and more integrated into different forms of human expression.

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