TinyExcel: Tiny incremental spreadsheet system
Is Excel real programming?

It is Turing-complete!
Encoded using "drag-down"

It is widely-used!
Simple, but can do a lot...
TinyExcel

What makes spreadsheets interesting?

- Most accessible programming tools!
- Program in a two-dimensional space
- Edit and view in the same environment
- Automatic and live sheet recomputation
# Technical Dimensions of Programming Systems

*(Jakubovic et al., 2023)*

## What matters about stateful interactive systems?

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Notation</th>
<th>Conceptual structure</th>
<th>Commmunability</th>
<th>Complexity</th>
<th>Errors</th>
<th>Adaptability</th>
</tr>
</thead>
<tbody>
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<tr>
<td></td>
<td></td>
<td>Technical Dimensions of Programming Systems</td>
<td></td>
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</tr>
</tbody>
</table>
Demo
Excel data exploration basics
Abstraction is hard

Drag-down for formulas makes abstraction easy

You only ever work with concrete values

Always see sample inputs & verify sample outputs
**TinyExcel**

Scope of the tiny version

- Two-dimensional space with references
- "Drag-down" to apply formula to a column
- Relative and absolute cell references
- Incremental computational engine
TinyExcel
Technical dimensions
The good and the bad

High usability
- Live exploratory programming
- Work with concrete values
- Learning from examples

High-profile errors
- "Growth in the time of debt" errors
- SEPT2, MARCH1 gene names
  (Septin, Membrane-Associated Ring Finger)
Confusing terminology

- **Exploratory programming**: Write, run, rethink with easy editing
- **Live programming**: See results of your program immediately
- **Live coding**: Run immediately, typically audio performance
- **Interactive programming**: Modify stateful programming system
Spreadsheets are...

Exploratory - easy to fiddle with data

Live - you see results (almost) immediately
Concreteness

Unimate industrial robot (1961)

Program by moving the robotic hand

Macro recording but done right
Concrete programming

Programming by demonstration
- Think macro recording
- How to generalize & re-apply
- "Drag down" in spreadsheets

Programming by example
- Generalize from input/output list
- Search for fitting program
- Also FlashFill in Excel
Demo
FlashFill in Excel
How people learn Excel

From existing spreadsheets
- View source of formulas
- Learn how functions work
- Logic needs to be visible!

Going to the expert
- Every office has Excel "guru"
- Needed for harder aspects
- Needed for use that does not have a "trace"
The grid power!

Humans are good at working with space

Programs are not typically spatial...

Grid is limiting, but powerful concept
TinyExcel

Learning from spreadsheets?

- More programming for non-programmers?
- Immediate live feedback is great!
- Abstractions from working with concrete values
- Programs should exist in understandable space
Could "normal" programming be more like this?

Demos by Bret Victor

Learnable Programming: Designing a programming system for understanding programs (online)
TinyExcel
Implementation techniques
Inter-cell dependencies

In what order to evaluate sheet?

Avoid evaluating a cell repeatedly!

What to re-evaluate when cells change?
Dependency graphs

Dependencies via cell and range references

Cyclic dependencies

Excel does a fixed maximal number of iterations

Explicit or implicit in code

Graph data structure vs. event listeners
Reactive programming

Different implementations

- Functional Reactive Programming
- ReactiveX (rxjs, RxJava, Rx.Net)
- Elm software architecture

Implementation techniques

- Push-based - Changes propagated from source
- Pull-based - Update required by the consumer
- Builder-based - Computation to be instantiated
TinyExcel
Implementation techniques

- Naive non-cached recursive starting point
- Cell is as graph node with "Updated" event
- Depending nodes listen, recompute & notify
- Tricky error and update handling...
The F# language
What we need for Excel
What we need to write Excel

Event handling
- F# events are objects (values)
- Can trigger & register handlers

More tips & tricks
- Collection processing
- Fancy patterns and active patterns

Finally a user interface?
- Would be nice, but setup costs high...
- Write sheet as HTML document & open
Generating lists

List comprehensions with the yield keyword

```plaintext
let worldInfo =
    [ yield addr "A1", Const(String "Continent")
      yield addr "B1", Const(String "Population (thousands)")
    for i, (cont, pop) in Seq.indexed continents do
      yield addr ("A"+string(i+2)), Const(String cont)
      yield addr ("B"+string(i+2)), Const(Number pop) ]
```

- **yield** adds another item to the list
- **for** and other constructs to write generators
- **Seq.indexed** trick to get item index
Demo

Extending the List module
// Declares event value
let evt = Event<int>()

// Trigger event
evt.Trigger(1)
evt.Trigger(2)
evt.Trigger(3)

// Object for listening
evt.Publish

// Listen and print
evt.Publish.Add(fun n ->
    printfn "Got: %d" n)

---

F# Events

Regular F# objects
Not special constructs
Correspond to IObservable in C#

Add and remove handlers using AddHandler and RemoveHandler
Demo

Working with F# events
Writing and opening HTML files

If you know C#, you can use other options too!

```csharp
let demo () =
    let f = Path.GetTempFileName() + ".html"
    use wr = new StreamWriter(File.OpenWrite(f))
    wr.Write("""<html><body><h1>Hello world!</h1></body></html>""")
    wr.Close()
    Process.Start(f)
```

- **GetTempFileName** gives you a file in TEMP folder
- **use** to make sure stream gets closed on error
- **Process.Start** can (sometimes) open files too
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Implementation structure
// In column, row format
// e.g. A1 becomes (1, 1)
type Address = int * int

// Note error is a value!
type Value =
  | Number of int
  | String of string
  | Error of string

// Operators are functions
type Expr =
  | Const of Value
  | Reference of Address
  | Function of string * Expr list

// Using immutable F# map
type Sheet = Map<Address, Expr>

Simple start

Standard ML-like expression language

References (instead of variables) are evaluated recursively

Sheet maps (filled) addresses to expressions
Expression and value are mutable. Updated triggered when they change.

```typescript
// CellNode
type CellNode =
  { mutable Value : Value
    mutable Expr : Expr
    Updated : Event<unit> }

// LiveSheet
// Immutable map of mutable cells
type LiveSheet =
  Map<Address, CellNode>
```

Version with the dependency graph

Value evaluated on creation which prevents circular refs

Expression stored "drag down" expansion

Updated event to notify of changes
Advanced extensions

Ranges and array values

```haskell
    type Value = // (...) | Array of Value list

    type Expr = // (...) | Range of Address * Address
```

Absolute addresses

```haskell
    type Index = Fixed of int | Normal of int
    type RawAddress = int * int
    type Address = Index * Index
```
Lab overview
TinyExcel step-by-step
TinyExcel - Basic tasks

1. Simple expression evaluator
   With grid references by cell address

2. "Drag down" formula expanding
   Relocating relative references in formula

3. Reactive event-based structure
   Refactoring code to use graph nodes

4. Reactive event-based computation
   Adding update event handling

5. Rendering sheets as HTML pages
   First step towards a user interface
TinyExcel - Bonus and super tasks

1. Absolute and relative addresses
   Alongside with improved "drag down"

2. Adding range selection and array values
   Required for the SUM function

3. Adding change visualization
   Tracking and showing what has changed

4. Full support for live editing
   Updating dependencies in the dependency graph
Where can you use this...

Financial systems
- Live financial models
- Incremental computation with dependency graph

Interesting programming systems
- Live programming systems
- Future more usable programming tools!
Conclusions

A tiny incremental spreadsheet system

- Computation as dependency graph
- Working with two-dimensional grid
- Good old (ML-like) expressions

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