IRIS-HEP
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LINTToRoot

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(apologies for the style of this talk… I got going and couldn't stop)

Declarative Analysis is an Old Concept

Specify what you want to do not how you want to do it

SQL, based on a CS paper from 1970, has been around since the early 70's.

Plot Missing E_T for events with 2 jets with $p_T > 40$ GeV and having at least 2 2 GeV tracks within $\Delta R < 0.2$ for full Run 2 analysis

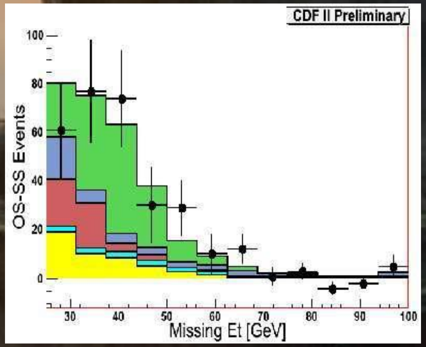
Infrastructure

Data Model

CPU Resources

GPU Resources

DOMA



Details

The Front End (Analysis Language + UI)

Plot Missing E_T for events with 2 jets with $p_T > 40$ GeV and having at least 2 2 GeV tracks within $\Delta R < 0.2$ for full Run 2 analysis

The Target
- The Missing E_T attribute of the event object
- Could be a tuple (Missing E_T, N_{Jets}, etc)
- Implied loop over events

Selection

Note:
- *Implied* double loop
  - Then over jets
  - Then over tracks
- Matching between levels

The Action
- Have to know how to plot
- Build a new TTree
- Generate a csv or numpy array
- Something new?

Imagine adding the word *Calibrated*

Details

Large local resource or on your laptop? Both?

Infrastructure

Data Model

CPU Resources

GPU Resources

DOMA

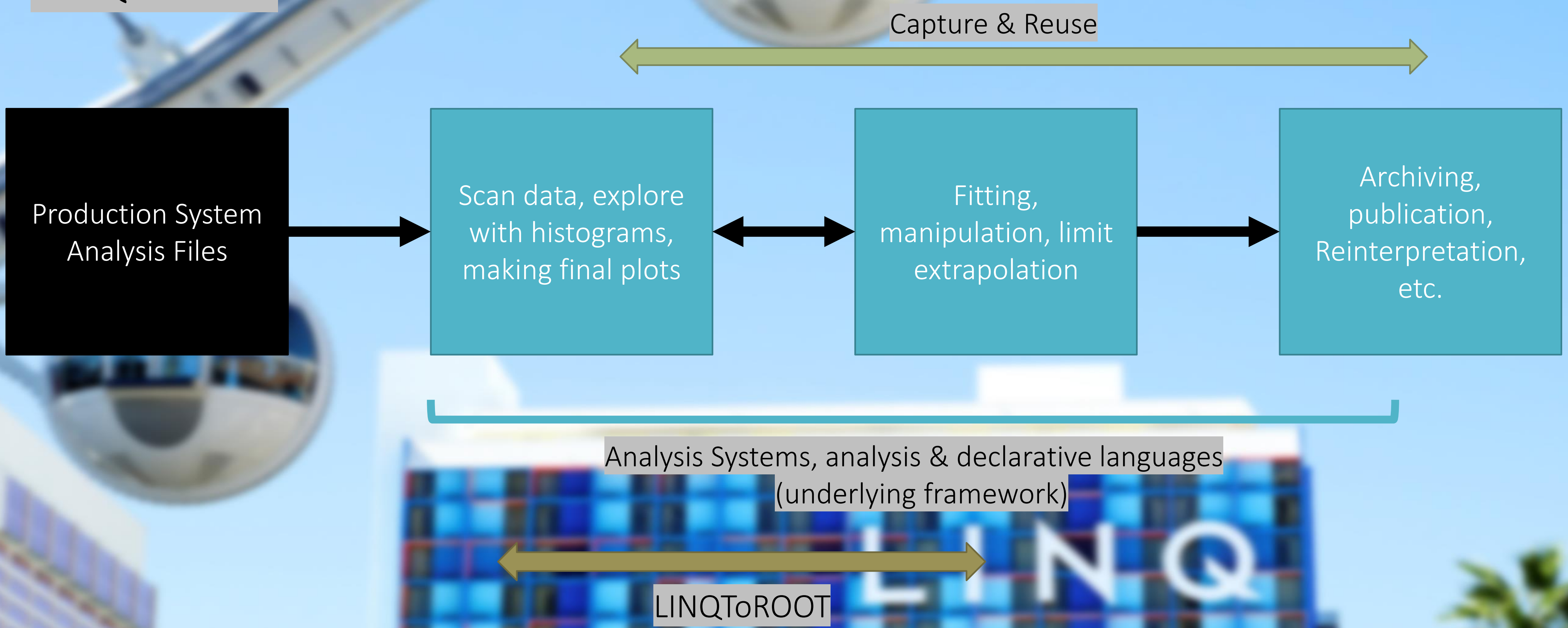
The Backend (Analysis System)

Data Model
- How data is structured
- How to code the "query"

DOMA
- Where to find the data
- Caching of intermediate results
- Picking up previously cached results

Scheduler
- Where to find the data
- Caching of intermediate results
- Picking up previously cached results

LINQToROOT



https://github.com/gordonwatts/LINQtoROOT

Query with Domain Knowledge

The electron is a first class object, specific to class of experiment.

Structured Query — numpy, pandas, RDataFrame, LINQ

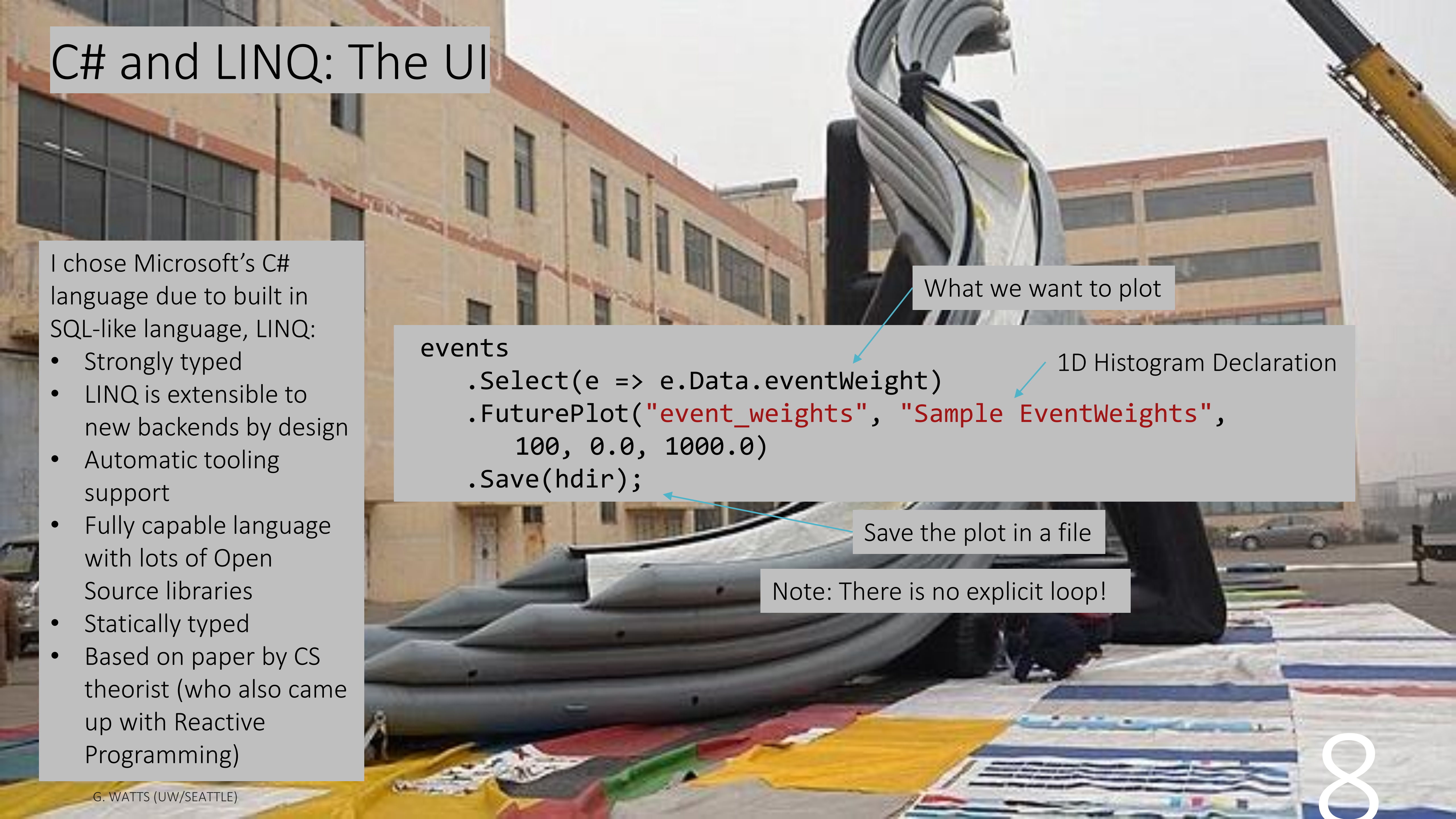
Data model contains object definitions, data structure is part of the language, experiment agnostic

In Memory/File Layout — TTree, numpy, jagged array

Data model contains all information, field and experiment agnostic

Domain Knowledge (↑)

C# and LINQ: The UI



I chose Microsoft's C# language due to built in SQL-like language, LINQ:

- Strongly typed
- LINQ is extensible to new backends by design
- Automatic tooling support
- Fully capable language with lots of Open Source libraries
- Statically typed
- Based on paper by CS theorist (who also came up with Reactive Programming)

What we want to plot

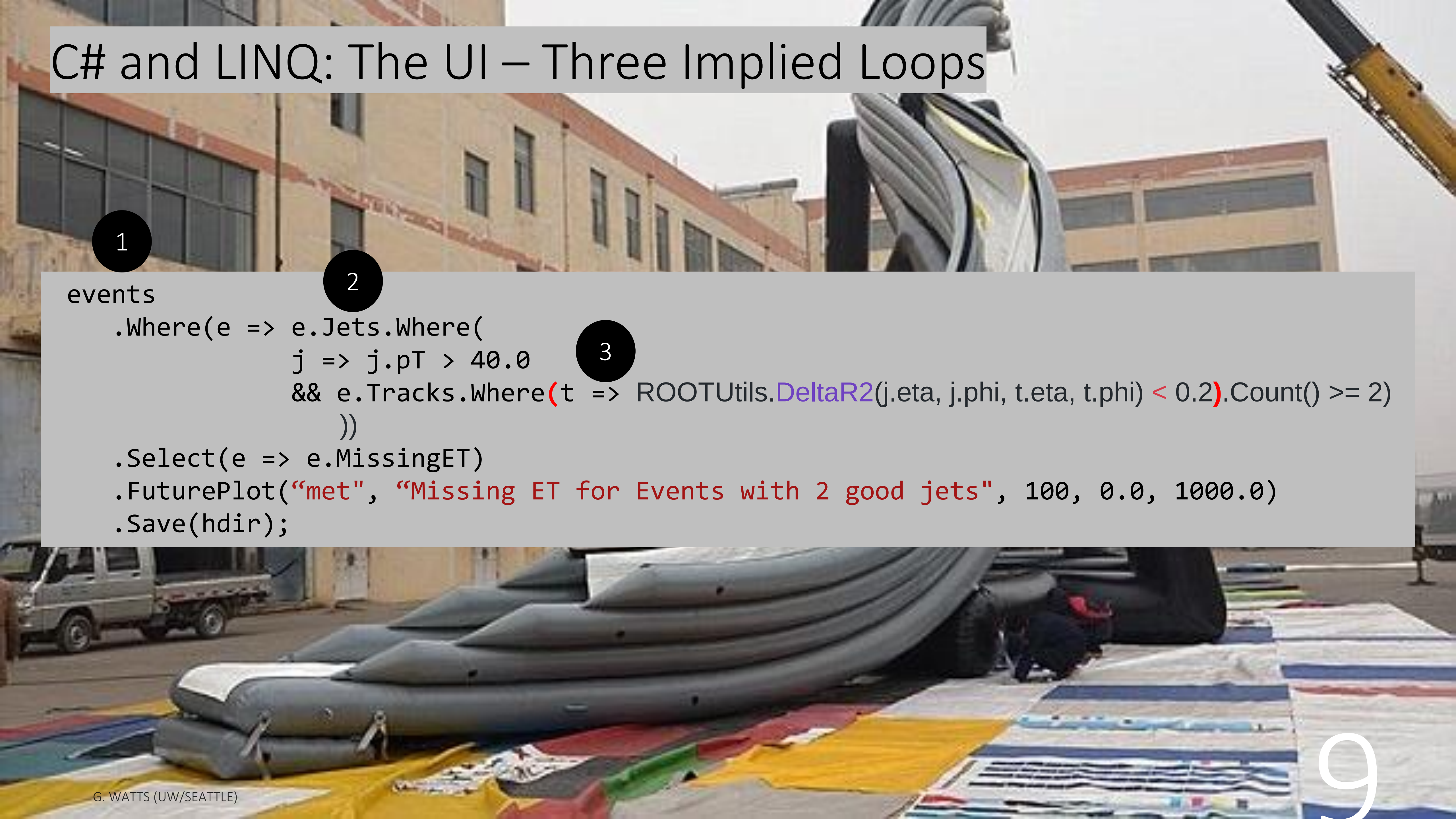
1D Histogram Declaration

```
events
    .Select(e => e.Data.eventWeight)
    .FuturePlot("event_weights", "Sample EventWeights",
        100, 0.0, 1000.0)
    .Save(hdir);
```

Save the plot in a file

Note: There is no explicit loop!

C# and LINQ: The UI – Three Implied Loops



1 2 3

```
events
    .Where(e => e.Jets.Where(
                j => j.pT > 40.0
                && e.Tracks.Where(t => ROOTUtils.DeltaR2(j.eta, j.phi, t.eta, t.phi) < 0.2).Count() >= 2)
                   ))
    .Select(e => e.MissingET)
    .FuturePlot(“met", “Missing ET for Events with 2 good jets", 100, 0.0, 1000.0)
    .Save(hdir);
```

LINQ Operations Implemented

[Complete List of LINQ Operations]

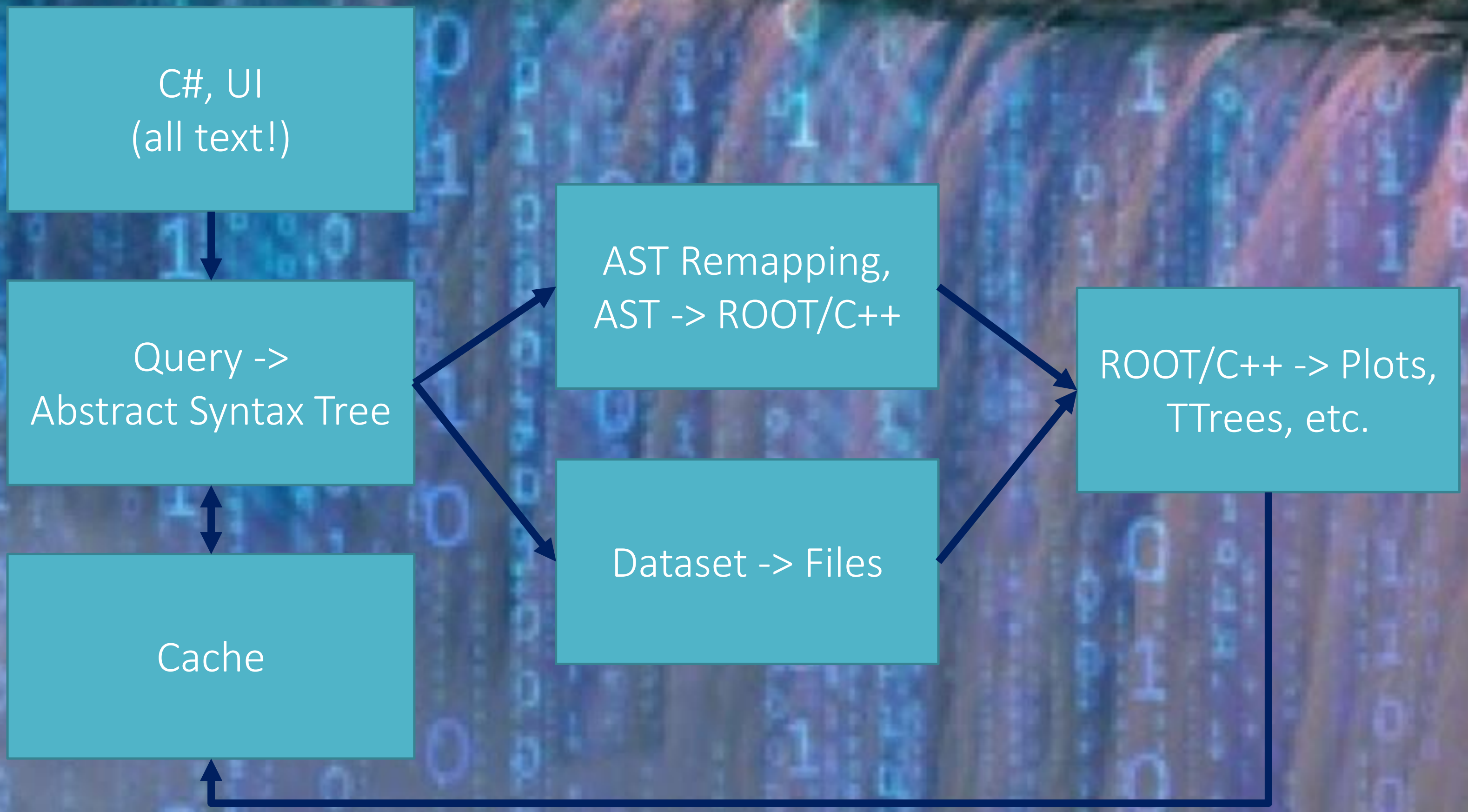
Sequence Operations

Name	Operation
Select	Apply a function to each object of the sequence rendering a new sequence (transformation): sequence of jet → sequence of jet.pt()
SelectMany	Unroll a loop: sequence of jet → sequence of tracks near each jet
Where	Filter: sequence of jets with pt > 50 GeV
OrderBy	Sort by some function of each object in the sequence (ascending or descending)
GroupBy	Group sequence into a sequence of sequences (jets between 10 and 40 GeV, 40 and 90 GeV, etc.).

Terminal Operations

Name	Operation
Aggregate	Accumulate, used as the basis of many other terminals: filling a histogram, calculate average, sum, etc.
All	True if every element of a sequence satisfies some condition
Any	True if any element of a sequence satisfies a condition
Count	Number of elements in a sequence
Empty	True if a sequence has no elements
First	First element of a sequence
Last	Last element of a sequence
Max, Min	Max or min value of some function over a sequence (you can get the object that satisfied this)
Skip/Take	Skip n elements or take n elements, or by a condition (take until/skip while)

Data Flow Through LINQToROOT



Data Flow Through LINQToROOT

C#, UI
(all text!)

- Needs to be 100% text (IMHO!!)
- Easy to compose streams of data and selections
  - Too easy? 1000's of histograms
- Provides for leaky abstraction
  - Here: including arbitrary C++ code
- Allows 1000's of plots to be made and results manipulated with futures
  - C# is not so strong with this (monad hell)
- LINQ is based on a Data Manipulation Language foundation, so is quite complete
  - Functional
  - Histogram filling is an *Aggregate* step
  - Feeds the whole OO was the largest mistake in the last xx years mythos.
- Full programming language allows for manipulation of histograms (do not want multistep analysis if can help it!)
- Strongly Typed!!!! No text strings, but this does cause some pain.

Data Flow Through LINQToROOT

Query -> Abstract Syntax Tree

- The AST contains all the information for the query
  - Source dataset
  - All selection cuts
  - Final desired product (a histogram, TTree, etc.)
  - Any data
    - A histogram that is used to re-weight events
- AST is unique for a query, it contains no “opaque” code
  - This does have restrictions on what type of C# code you can use.
  - C# supports generating AST for lambda functions as part of the language standard. **This is a key feature to make this work.**
- AST (and C#) expressive enough to do raw ATLAS xAOD.
- Vision: cut/paste text representation of AST into tool and it generates the code (Data Preservation, Jupyter notebook to repro a plot, etc.). A Juypter Notebook…
- AST – could be sent over wire to **Analysis System Server**.

Data Flow Through LINQToROOT

Cache

- The Cache uses the AST as a key
- Product is stored (histogram in a ROOT file, csv file, etc.)
- Look up and load was less than 10 ms.
  - Bulk of time was translating ROOT histograms to a hash when they are part of the AST
  - And opening and loading a ROOT file (every histo was stored in an individual file)
  - Rerunning 1000 plots still took 4-5 minutes (still too slow).
- Cache worked across different code bases as long as AST matched
- Was localized to a single machine (unfortunately).
- Obvious place to work with DOMA folks to understand how to do this better

Data Flow Through LINQToROOT

AST Remapping,
AST -> ROOT/C++

- Remapping performs arbitrary transformations on the AST
  - Take a flat ntuple and make it look like it has objects (electron pt, eta, phi are separate branches, but in C# can loop over electrons and look at pT, etc.).
  - Important to let user code in way that promotes “physics” thinking and the backend to run as efficiently as possible.
  - Original reason: our group was writing out flat ntuples and that drove my brain nuts.
  - Many other transformations possible, but not explored.
- AST’s from different queries can be combined to make scan over data more efficient
- AST’s can be optimized (e.g. loop invariants, common calculations). This is where most of my bugs existed and bulk of unit tests (~300 or 400).
- C++ code written using the visitor pattern on the AST.

Data Flow Through LINQToROOT

Dataset -> Files

- When I ran at University of Washington or at CERN I'd get the same thing
  - Even though the files were located on different computers
- Tools to copy datasets
- Tools to submit jobs to take production skims and turn them into flat ntuples
  - Allowed me to track, with git, analysis from production system to plots
- This was an ad-hoc system!
  - Obvious place to work with DOMA folks and make something that works well

Data Flow Through LINQToROOT

ROOT/C++ -> Plots, TTrees, etc.

- Multiple backends
  - Run on my windows machine
  - Run on a Linux partition in my windows machine
  - Run on Linux via SSH
  - Run on multiple Linux machines (e.g. a really simple PROOF).
- AST told you what leaves were going to be touched, so could pre-configure.
- For the most part, the system was very simple.
- If the C++ didn't compile, I considered that a bug in LINQToTTree
  - The UI (or C#) should catch all errors.
  - This was to help prevent the abstraction from leaking
  - Also… C++ compiler error messages…
  - Mostly because my optimizer had bugs in it

Where to next?

- Can this be done in python?
- Can a similar language drive an xAOD, Flat TTree, and columnar pandas like analysis?
    - Confident of the first two
- Python has different idioms and abilities vs. C#
    - Can the UI be made concise and clear?
- Can an AST fully express queries?
    - Over the wire?

608 lines (607 sloc) | 23.1 KB

Raw | Blame | History

[See full example](#)

Import into Pandas from an ATLAS xAOD

This is a sample script that uses the ad-hoc analysis library to extract jet pt's from an ATLAS xAOD file.

Setup and Config

In [1]:
```
fname = r"file://G:/mc16_13TeV/AOD.16300985._000011.pool.root.1"
```

In [2]:
```
%%time
from clientlib.DataSets import EventDataSet
```

```
Wall time: 645 ms
```

Import the events into a Pandas array.

This requires docker installed. As this is a proof of principle, a lot of stuff is hardwired.

First thing we do is turn a dataset into an implicit stream of events.

In [3]:
```
%%time
f = EventDataSet(fname)
events = f.AsATLASEvents()
```

```
Wall time: 0 ns
```

- Query in a simple AST
- Runs full ATLAS environment in docker
- Exports a root file and uses uproot to import it as a Pandas dataframe

- Have just started a [github repo](#) to explore this.
- Prototype quality code
- Hope to have rough answers to most questions in a month or two

Final Thoughts

- I am a firm believer in this approach
  - It is definitely not without its problems
  - For me this started as a grumpy old professor research project: make it easy!
- I think we must move towards splitting the analysis language and server
  - Common protocol for the field?
  - Even locally (everyone can run docker)
- C# as a choice
  - One of the most expressive imperative OO languages I've used (LINQ, pattern matching in code, garbage collected)
  - Availible in Linux – but known well by a minority of physicists
  - Unfortunately, no other language has the proper set of features built into the language standard

- High level specification of analysis language
  - DOMA experts can work on back ends
  - Anyone can take advantage of their own language if they want
  - Allows independent advancement
  - AL could be quite powerful outside of HEP analyzing structured data
- Pain Points
  - 4-5 minutes to re-run 1000 histograms too slow
  - Histograms
    - Common axes as building blocks
    - Change title or axis label and binary representation changes (caching).
  - Cache was one machine only
  - What if you want to change a base line cut and look at one histo?
    - That takes 20 minutes, but all 1000 will change, and now you are looking at 5-6 hours

Backup

Sense of Scale

Number of events (signal + background + control)	~ 2 billion
GRID Data Samples	~ 200
Size of input files	1-2 TB
Number of leaves in processed ntuples	~340
Plots made per job	~400-800
Number of users	1
Number of Developers	1

A small analysis by HL-LHC standards…

But a decent sized one for Run 1 and Run 2

Published ~~2~~ 3 papers and 2 ATLAS CONF notes in part using this tool.