Software Design in the Radical Pie Equation Editor

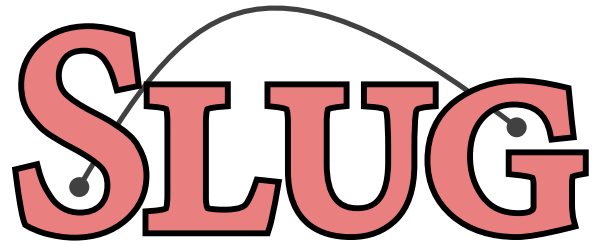
Eric Lengyel, Ph.D.

Better Software Conference 2026

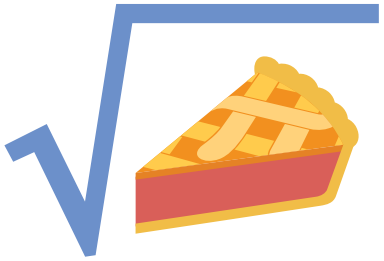
What’s the difference between a mathematician and a computer scientist?

Mathematicians love mathematics,
and computer scientists hate computers.

About the Speaker



- Working in industry since 1994

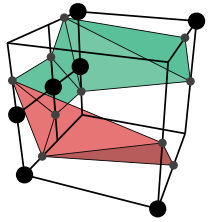


- Former Sierra, Apple, Naughty Dog

- Running own business since 2005
  - C4 Engine
  - Slug Library
  - Radical Pie

OpenGEX

- Writes books, occasionally teaches

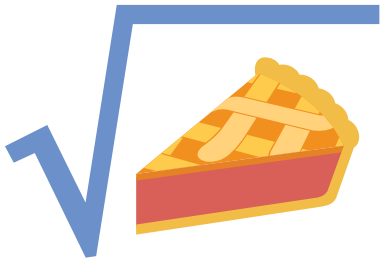


TRANSVOXEL

About This Talk

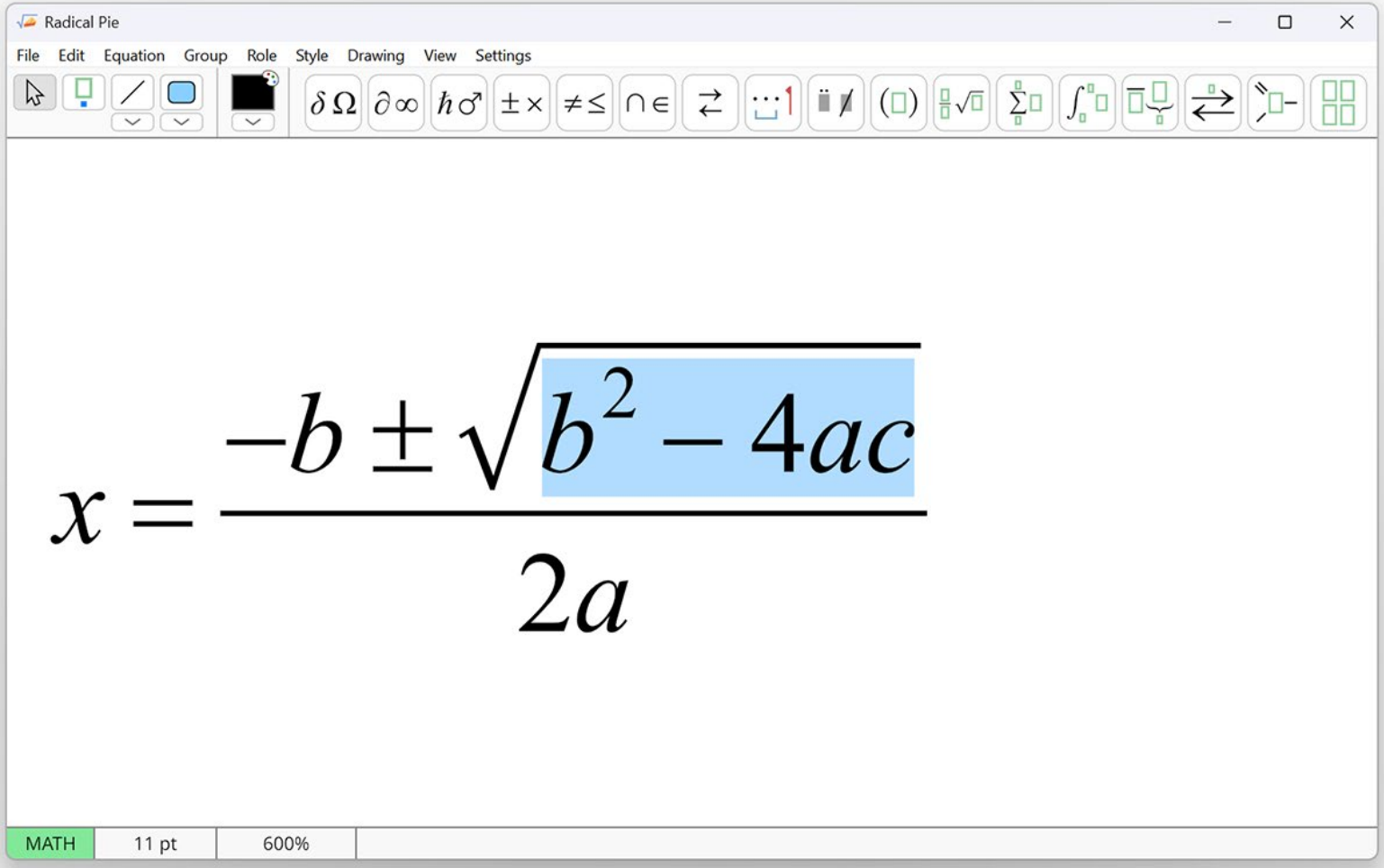
- Case study of productivity software built from scratch
- Discusses high-level software architecture of Radical Pie
- Highlights minimal dependencies, homegrown tech
- Focuses on quality, usability, compatibility

About Radical Pie

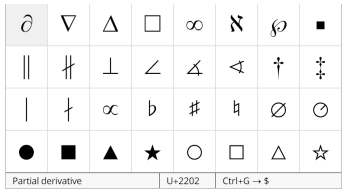


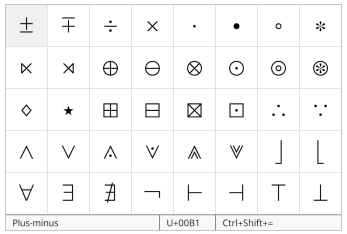
- Radical Pie is a professional equation editor
- Runs as standalone application on Windows 10/11
- Integrates with Microsoft Word through OLE
- Fully WYSIWYG with instant in-place results
- Operates in MATH, CHEM, and TEXT modes

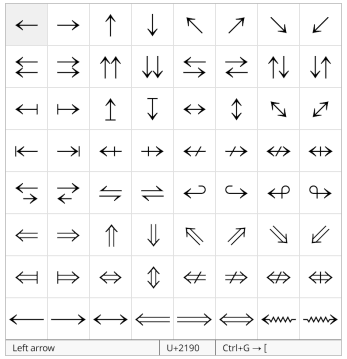
Editor Window

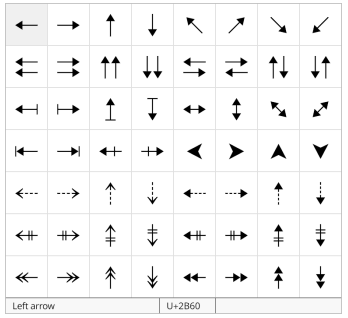


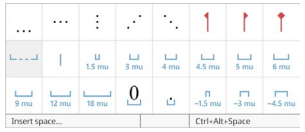
17 Symbol / Structure Palettes

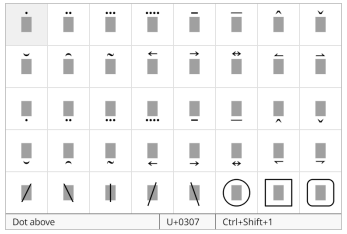


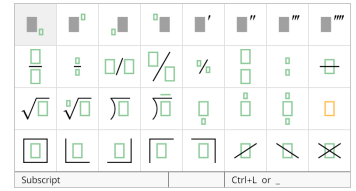


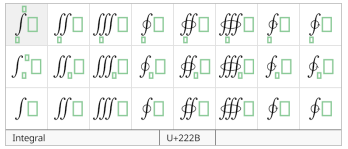


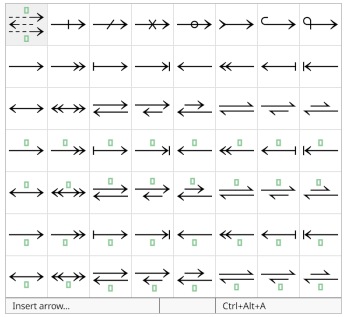


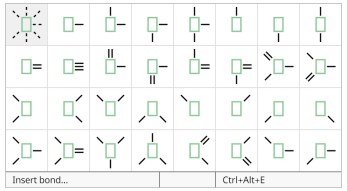


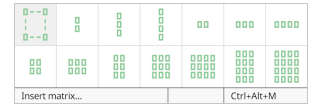




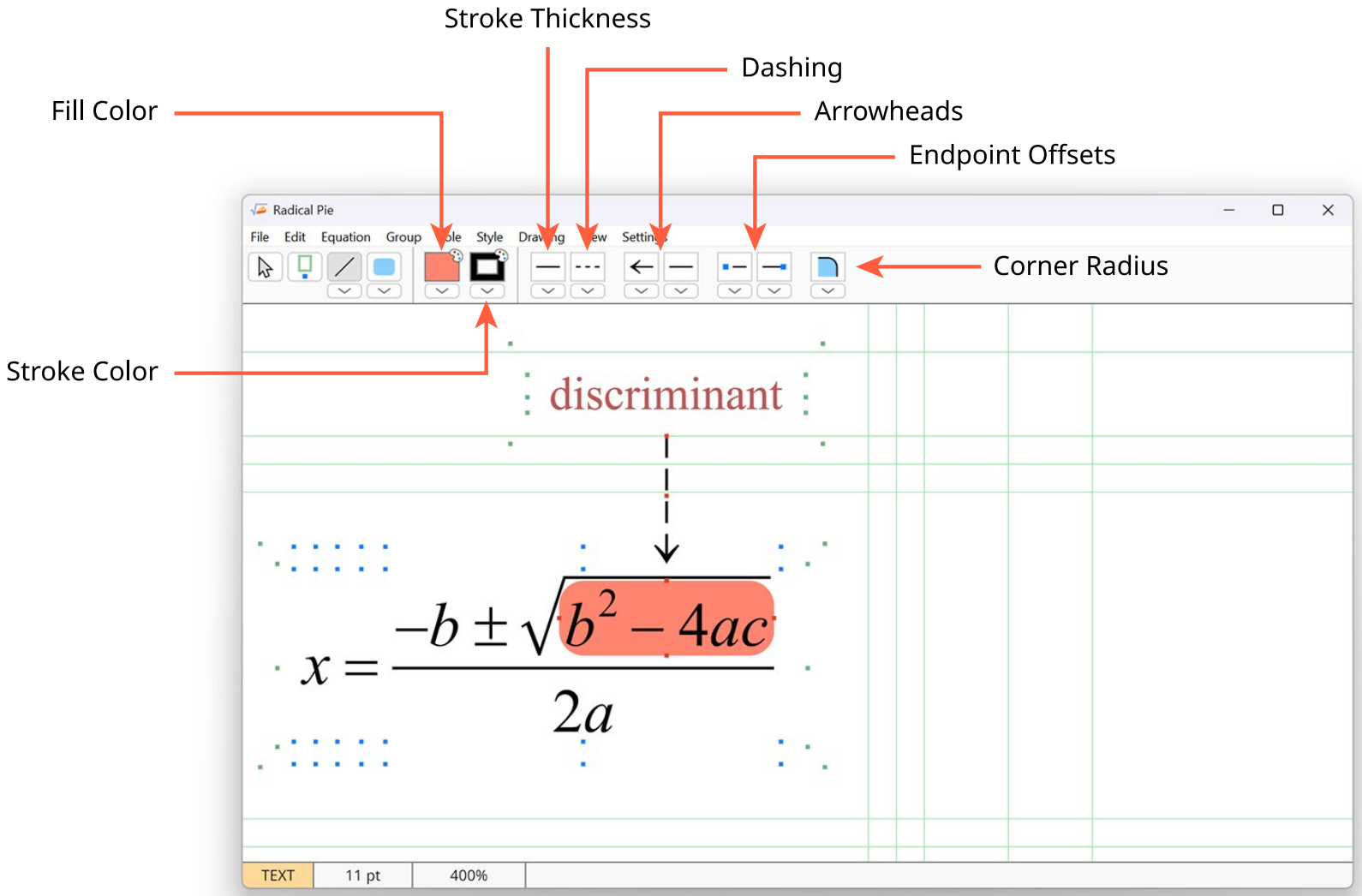




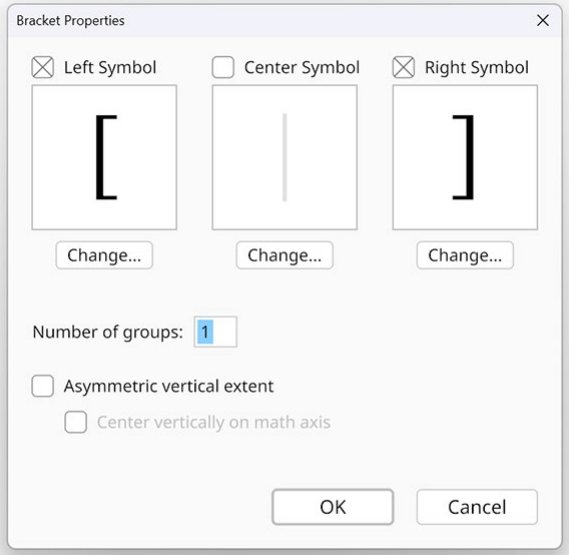


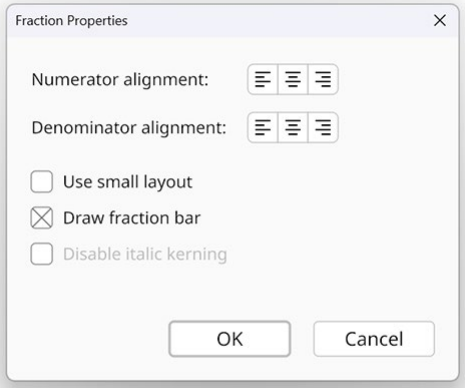


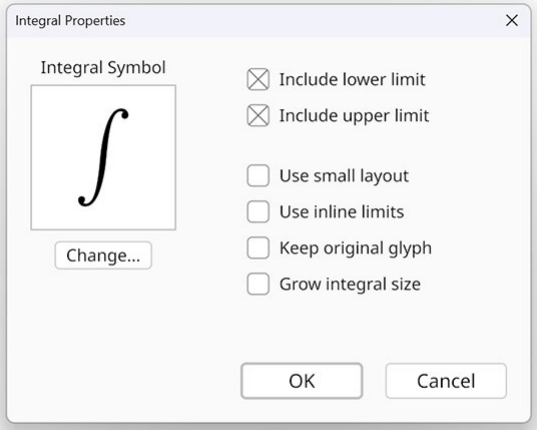
Drawing and Annotation Tools

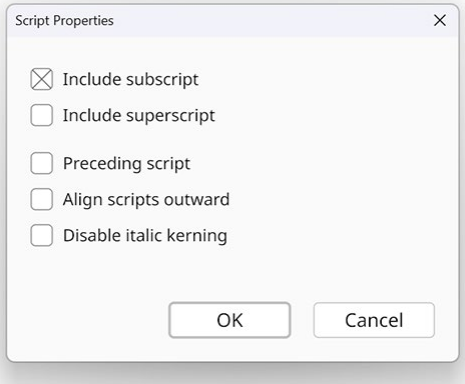


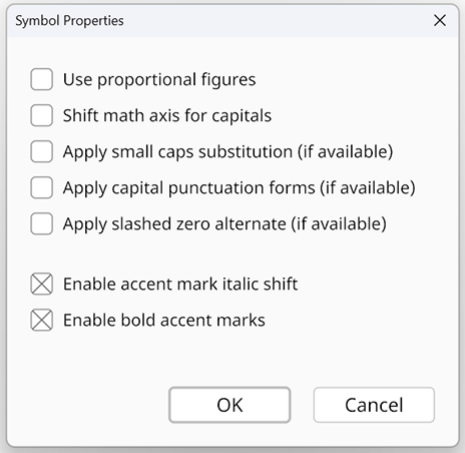
Properties Dialogs

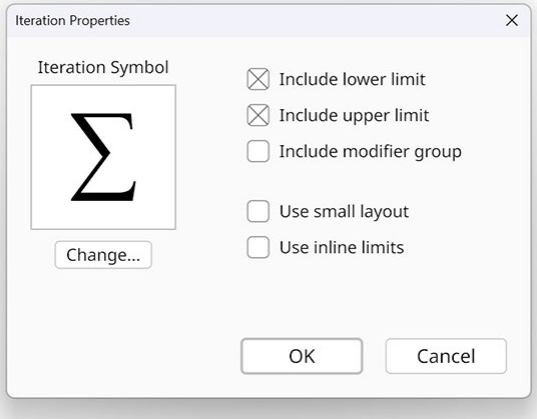




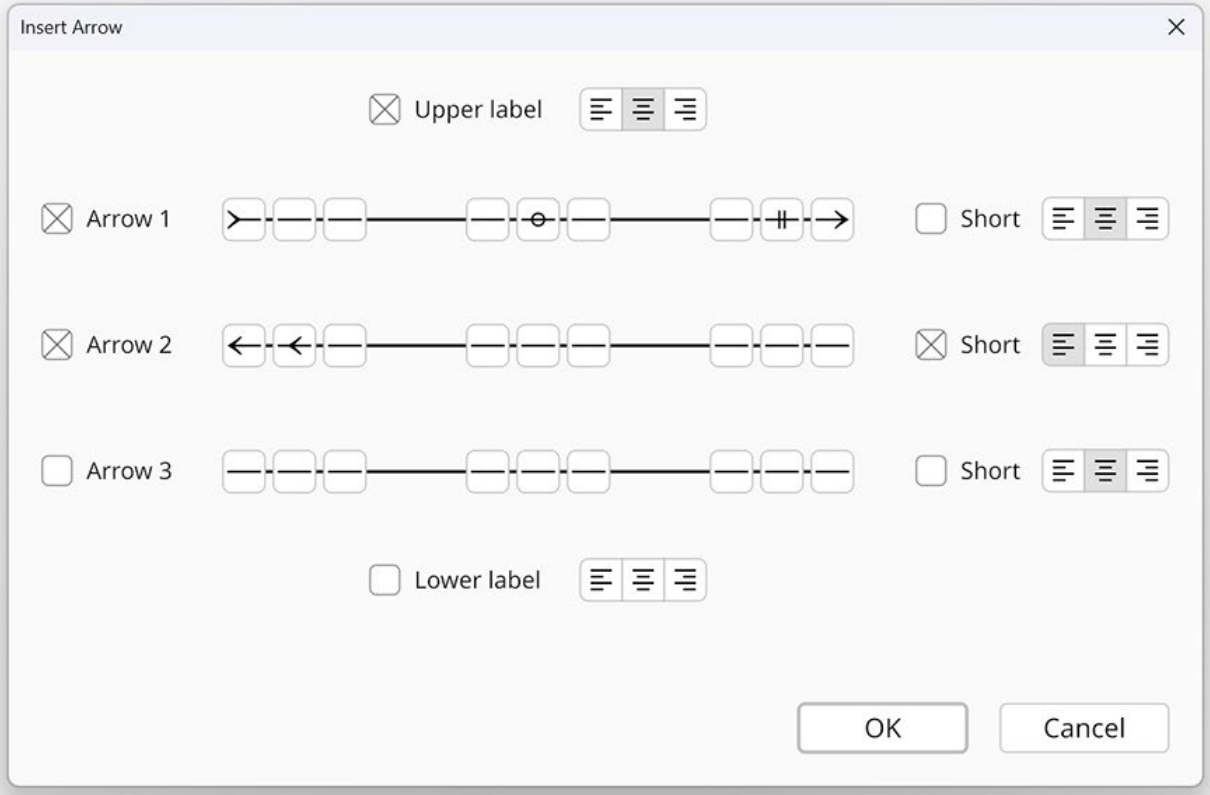


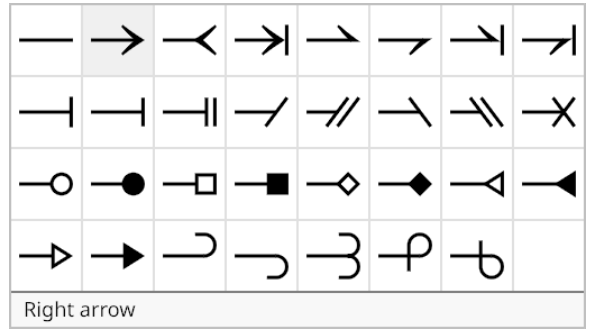




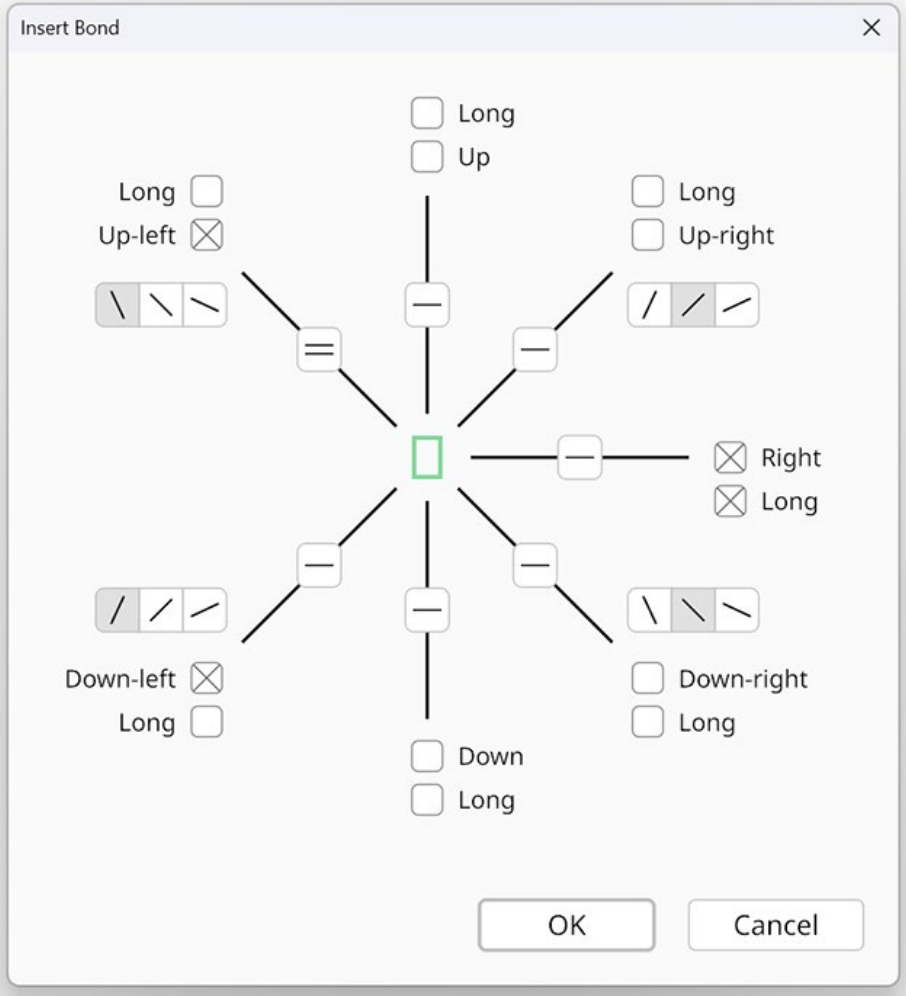


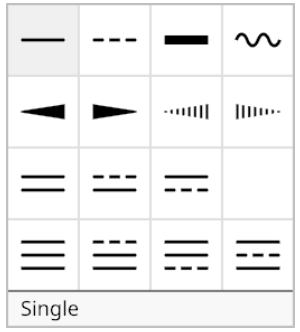
Arrow Builder



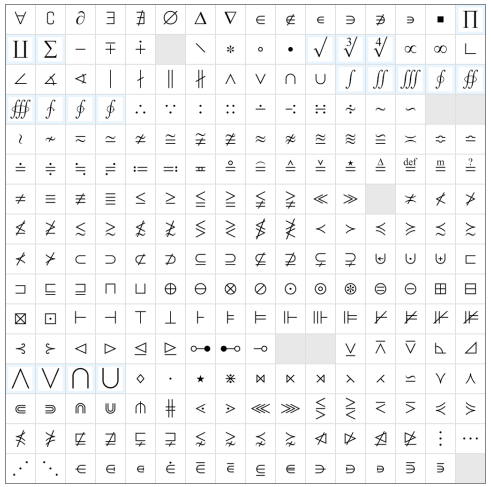


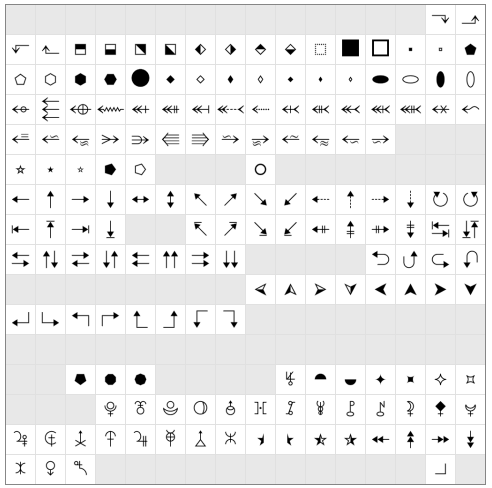
Chemical Bond Builder

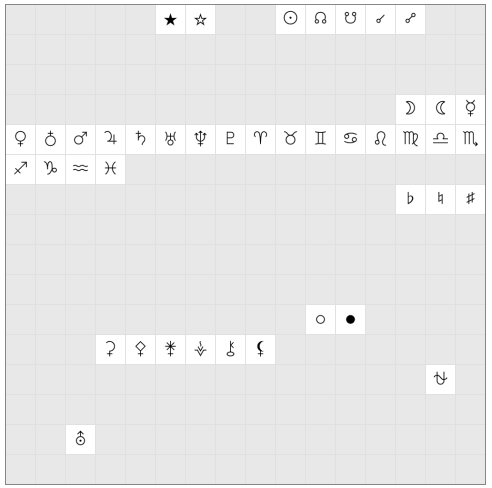


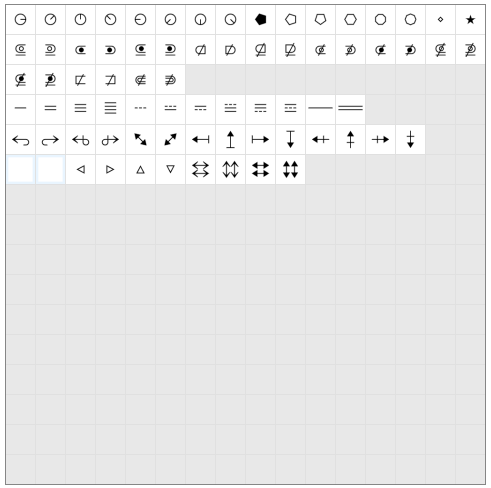


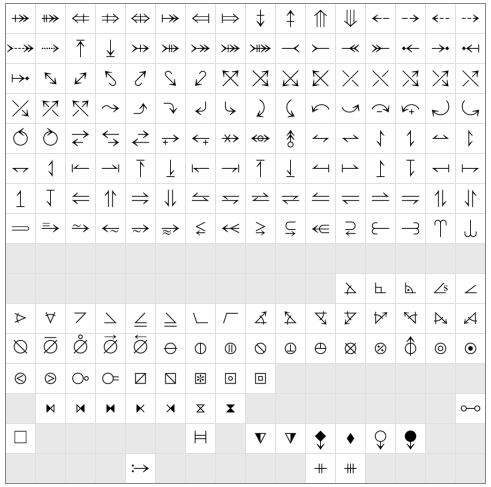
Radical Font, ~1400 Glyphs

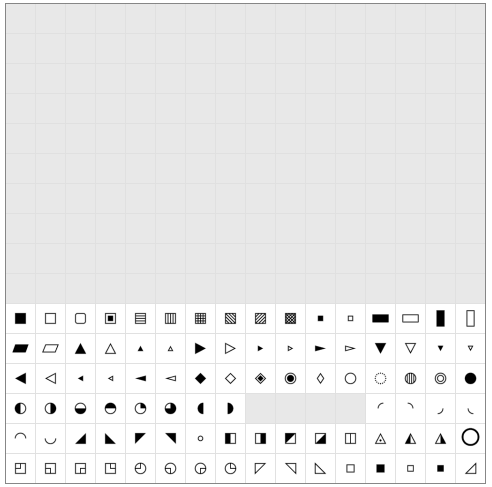


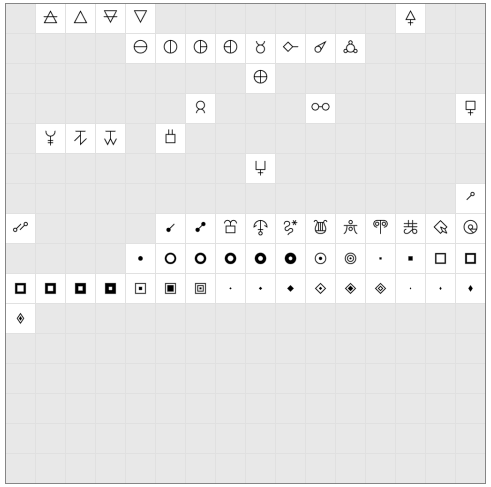












Motivation for Making Radical Pie

- Just use LaTeX!
- Most people who make that comment weren't born yet when I started using LaTeX in the early 90s.
- LaTeX was designed in the 1980s for the computers of the time.
  - Predates Unicode
  - Predates TrueType fonts
- We can do a lot better now

LaTeX

- LaTeX is a complex markdown language
- You write code, and it goes through a compiler
- You find out you have errors like unmatched braces
- Or an equation doesn’t appear as intended
- You fix the problems and repeat the cycle

LaTeX

- LaTeX is missing lots of stuff
- If what you want isn’t in there, you’ll be spending time hunting for the right packages
- Then you’ll be dealing with conflicts, font limitations, etc.
- This all takes away from time you could be spending getting actual work done

LaTeX in MathJax

- Actual equation from PGA website:

$$\left\Vert\mathbf Q\right\Vert_\unicode["segoe ui symbol"]{x25CB} = \sqrt{\mathbf Q \mathbin{\unicode["segoe ui symbol"]{x27C7}} \smash{\mathbf{\underset{\Large\unicode{x7E}}{Q}}} \vphantom{\mathbf{\tilde Q}}} = {\large\unicode{x1D7D9}}\sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$

- LaTeX code:

```
$$\left\Vert\mathbf Q\right\Vert_\unicode["segoe ui symbol"]{x25CB} = \sqrt{\mathbf Q
\mathbin{\unicode["segoe ui symbol"]{x27C7}} \smash{\mathbf{\underset{\Large\unicode{x7E}}{Q}}}
\vphantom{\mathbf{\tilde Q}}} = {\large\unicode{x1D7D9}}\sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$
```

LaTeX Tediousness

- Takes 7–8 minutes to enter this LaTeX code
  - Assuming you already know how to do the things you want to do
  - Assuming you don’t need to look up any Unicode values
  - Including time spent correcting errors

```
$$\left\Vert\mathbf Q\right\Vert_\unicode["segoe ui symbol"]{x25CB} = \sqrt{\mathbf Q
\mathbin{\unicode["segoe ui symbol"]{x27C7}} \smash{\mathbf{\underset{\Large\unicode{x7E}}{Q}}}
\vphantom{\mathbf{\tilde Q}}} = {\large\unicode{x1D7D9}}\sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$
```

$$\left\Vert\mathbf Q\right\Vert_\unicode["segoe ui symbol"]{x25CB} = \sqrt{\mathbf Q \mathbin{\unicode["segoe ui symbol"]{x27C7}} \smash{\mathbf{\underset{\Large\unicode{x7E}}{Q}}} \vphantom{\mathbf{\tilde Q}}} = {\large\unicode{x1D7D9}}\sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$

LaTeX Tediousness

- Same equation entered with Radical Pie GUI in 35 seconds:

$$\|\mathbf{Q}\|_{\bigcirc} = \sqrt{\mathbf{Q} \breve{\vee} \underset{\sim}{\mathbf{Q}}} = \mathbb{1}\sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$

- MathJax output for comparison:

$$\|\mathbf{Q}\|_{\bigcirc} = \sqrt{\mathbf{Q} \breve{\vee} \underset{\sim}{\mathbf{Q}}} = \mathbb{1}\sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$

LaTeX Usability

- Extremely error-prone
- Inconsistent package support across implementations
- Not WYSIWYG
  - Yes, there are instant-compile wrappers, but you're still writing code, not editing visually in place
- Worst of all, there is no *discoverability* of available features

Visual Equation Editors

- Writing code for equations is like drawing diagrams with text containing the vertex coordinates for different shapes
- You can do this, and you'll have full control, but it's extremely tedious, error-prone, and time-consuming
- Most people would prefer to just get their real work done!

Visual Equation Editors

- Visual equation editors have been around for a long time
  - There are lots of options to choose from today

- However, almost all of them are shit
  - Low-quality equation layout
  - Poor usability
  - Poor interoperability
  - Missing features
  - Buggy as hell

- People get the impression that there are no good solutions
  - Brings us back to “Just use LaTeX”

MathType

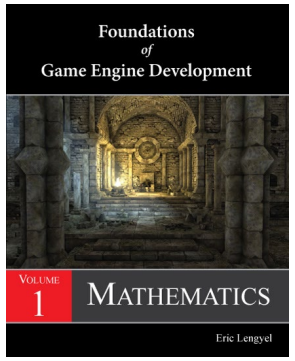
- Pro version of equation editor shipped with Word in 90s
- Comprehensive feature set
- High-quality output
- Excellent integration with Microsoft Word

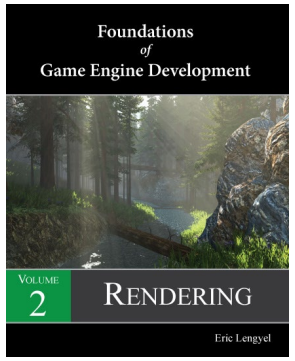
MathType

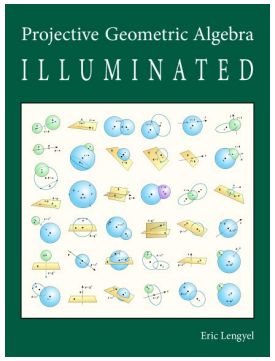
- I started using MathType with Word around year 2000
- Vastly more productive compared to LaTeX
- Proficiency with MathType and Word style system was enough to produce highly professional results
- Helped to know what parts of Word to avoid

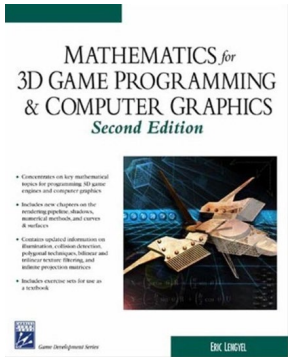
MathType + Word

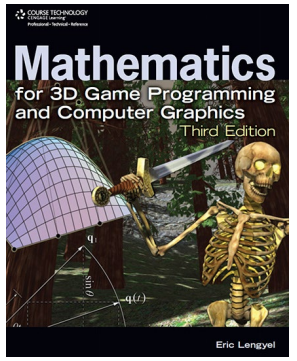
- Used to typeset final print proof for these books:

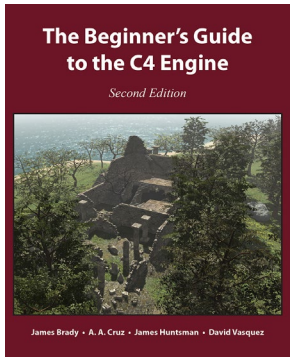


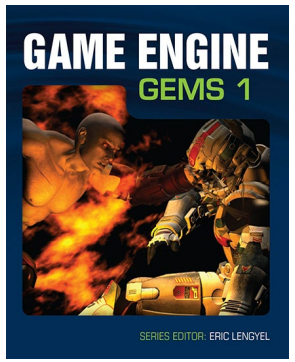


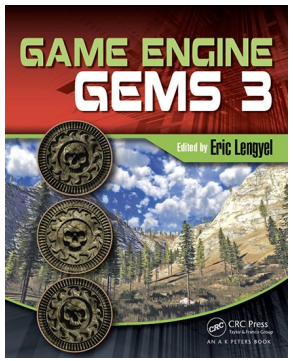


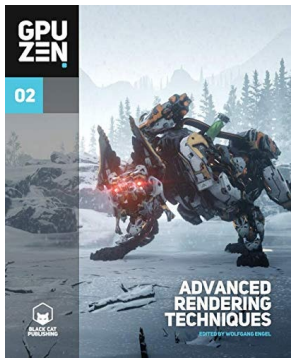


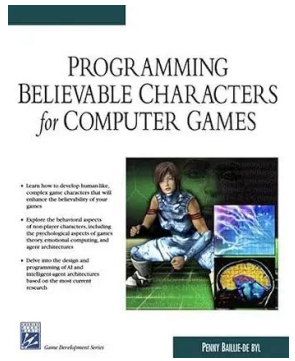


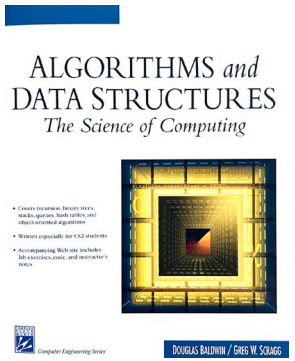












MathType Demise

- 20 years ago, MathType was da bomb
- Somewhere around 2010, it stopped getting significant updates
- Design Science sold to Wiris in 2017
- MathType was replaced by an inferior application that was then rebranded as MathType

MathType Limitations

- Outdated Unicode support
  - Confused by fonts with characters outside BMP
- Copy/paste to other applications not always successful
- No support for simple equation boxing
- Certainly no support for drawings and annotations
- GUI showing its age

Office Math

- Starting in 2007, Microsoft Office has shipped with its own integrated equation editor
- It’s clunky, buggy, slow, ugly, and has a limited feature set
- It can only use fonts containing a MATH table
  - Inexcusable failure of both engineering and management
  - For most users, this forces the Cambria font (but a few others exist)
- Good Unicode support, though!

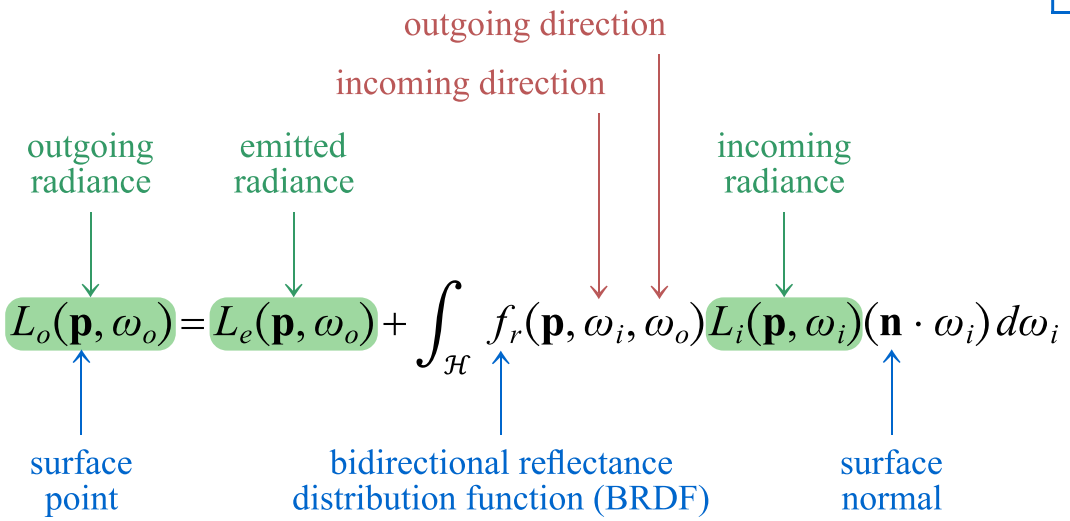
Needed Features

- Full Unicode support
- Native drawing tools
  - Had to copy equation to Illustrator, draw boxes, arrows, annotations
  - Then paste result into Word as SVG picture -- gets wrong DPI
  - No longer live, editable equation -- had to start over to make changes
  - Could do simple box in Word, but required hacks and was buggy
- Even better output quality and control over appearance
- Recognition of surrounding font size in Word

Needed Features

$$\mathbf{D}(\tau) = \boldsymbol{l}\sin\left(\frac{1}{2}\gamma\tau\dot{\phi}\right) + \mathbb{1}\cos\left(\frac{1}{2}\gamma\tau\dot{\phi}\right) - \left(\frac{1}{2}\gamma\tau\dot{\delta}\boldsymbol{l}^{\star}\wedge\mathbf{e}_0\right)\cos\left(\frac{1}{2}\gamma\tau\dot{\phi}\right) - \frac{1}{2}\gamma\tau\dot{\delta}\mathbf{e}_0\sin\left(\frac{1}{2}\gamma\tau\dot{\phi}\right)$$
$$-\frac{1}{2}\gamma c\tau\left[\boldsymbol{l}\sin\left(\frac{1}{2}\gamma\tau\dot{\phi}\right) + \mathbb{1}\cos\left(\frac{1}{2}\gamma\tau\dot{\phi}\right)\right]\vee\mathbf{e}_{321}.$$

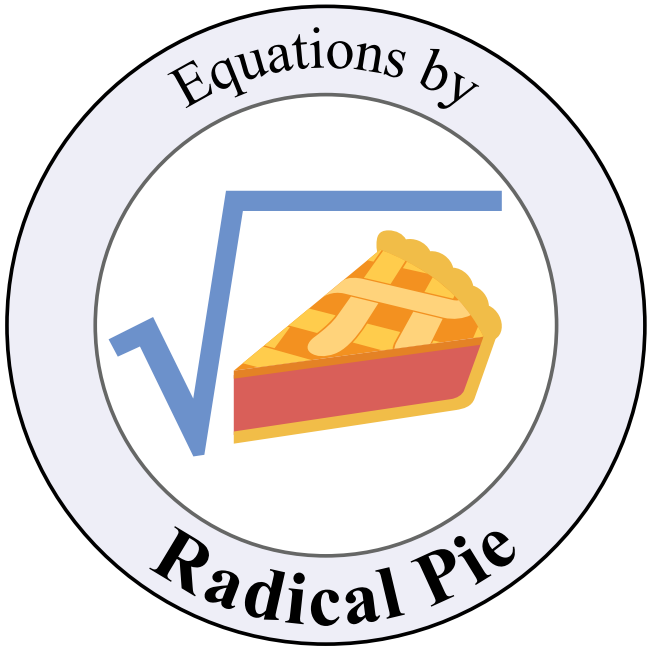
$$\hat{\Phi}_g(\alpha) = \frac{\Phi_g(\alpha)}{\Phi_g(0)} = \left(\frac{1-g}{\sqrt{1+g^2-2g\cos\alpha}}\right)^3.$$



Needed Features

- A modern graphical equation editor with all these features did not exist
- If I wanted it, then I would have to build it myself
- Fortunately, this kind of application is right up my alley
- Didn’t hurt that I spent the previous 8 years working on what would be essential equation editor functionality: *font rendering*

Radical Pie



$$\mathbf{c} = c_{gx}\mathbf{e}_{423} + c_{gy}\mathbf{e}_{431} + c_{gz}\mathbf{e}_{412} + c_{gw}\mathbf{e}_{321} + c_{vx}\mathbf{e}_{415} + c_{vy}\mathbf{e}_{425} + c_{vz}\mathbf{e}_{435} + c_{mx}\mathbf{e}_{235} + c_{my}\mathbf{e}_{315} + c_{mz}\mathbf{e}_{125}$$

Cocarrier Direction · Carrier Plane · Cocarrier Moment · Flat Line (when $c_{gx} = c_{gy} = c_{gz} = c_{gw} = 0$)

$$\|\mathbf{T}(\tau)\|_{\bullet} = \frac{1}{2}\sqrt{c^2dt^2 - dx^2 - dy^2 - dz^2}$$

$$M_{\odot} = 1.989 \times 10^{30}\,\mathrm{kg}$$
$$R_{\odot} = 6.957 \times 10^{8}\,\mathrm{m}$$

$$M_{\oplus} = 5.972 \times 10^{24}\,\mathrm{kg}$$
$$R_{\oplus} = 6.3781 \times 10^{6}\,\mathrm{m}$$

$$\left(\int_{-\infty}^{\infty} e^{-x^2}dx\right)^2 = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} e^{-(x^2+y^2)}dx\,dy = \int_0^{2\pi}\int_0^{\infty} e^{-r^2} r\,dr\,d\theta = \pi\int_{-\infty}^{0} e^{s}\,ds = \pi \qquad s = -r^2$$

$$\mathbf{a} \underset{k}{\barwedge} \mathbf{b} = \sum_{\mathbf{c}\in\mathcal{B}_k} (\underline{\mathbf{c}} \vee \mathbf{a}) \wedge (\mathbf{b} \vee \mathbf{c}^{\star})$$

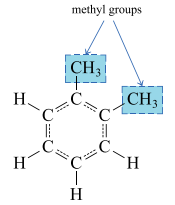
$$\mathbf{a} \barwedge \mathbf{b} = \sum_{k=0}^{n} (-1)^{k(k-1)/2}\, \mathbf{a} \underset{k}{\barwedge} \mathbf{b}$$

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{B} = \mu_0\mathbf{J} + \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t}$$

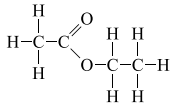
Ricci tensor · Metric tensor · Scalar curvature · Einstein tensor

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R$$
$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

$$6\,CO_2 + 6\,H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6\,O_2$$



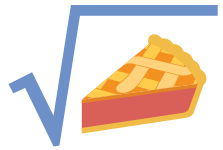
$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

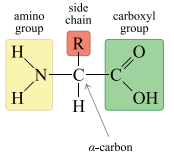


$$\zeta(s) = \sum_{n=1}^{\infty} \frac{1}{n^s} = 1 + \frac{1}{2^s} + \frac{1}{3^s} + \cdots$$

outgoing radiance · emitted radiance · outgoing direction · incoming direction · incoming radiance · surface point · bidirectional reflectance distribution function (BRDF) · surface normal

$$L_o(\mathbf{p}, \omega_o) = L_e(\mathbf{p}, \omega_o) + \int_{\mathcal{H}} f_r(\mathbf{p}, \omega_i, \omega_o) L_i(\mathbf{p}, \omega_i)(\mathbf{n} \cdot \omega_i)\, d\omega_i$$

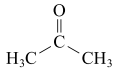




$$\begin{bmatrix} \leftarrow & \mathbf{T}' & \rightarrow \\ \leftarrow & \mathbf{N}' & \rightarrow \\ \leftarrow & \mathbf{B}' & \rightarrow \end{bmatrix} = \begin{bmatrix} 0 & \kappa & 0 \\ -\kappa & 0 & \tau \\ 0 & -\tau & 0 \end{bmatrix} \begin{bmatrix} \leftarrow & \mathbf{T} & \rightarrow \\ \leftarrow & \mathbf{N} & \rightarrow \\ \leftarrow & \mathbf{B} & \rightarrow \end{bmatrix}$$

$$\Phi_g(\alpha) = \frac{1 - g^2}{4\pi(1 + g^2 - 2g\cos\alpha)^{3/2}}$$

$$f_{\text{linear}}(c) = \begin{cases} \dfrac{c}{12.92}, & \text{if } c \le 0.04045; \\ \left(\dfrac{c + 0.055}{1.055}\right)^{2.4}, & \text{if } c > 0.04045. \end{cases}$$



$$\mathbf{M} = \begin{bmatrix} 1 & & & & & & & \\ & \mathbf{m} & & & & & & \\ & & \mathbf{m} & & & & & \\ & & & \mathbf{m} & & & & \\ & & & & C_2(\mathbf{m}) & & & \\ & & & & & C_2(\mathbf{m}) & & \\ & & & & & & C_2(\mathbf{m}) & \\ & & & & & & & \det \mathbf{m} \end{bmatrix}$$

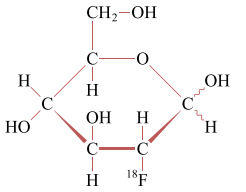
$\mathbf{1}$ $\mathbf{e}_1$ $\mathbf{e}_2$ $\mathbf{e}_3$ $\mathbf{e}_{23}$ $\mathbf{e}_{31}$ $\mathbf{e}_{12}$ $\mathbb{1}$

← scalar · ← vector · ← bivector · ← antiscalar

Theorem. If p is a prime number that does not divide an integer a, then $a^{p-1} \equiv 1 \pmod{p}$.

$$\mathcal{I} = \sum \gamma m$$

$$\begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 & -x & -y & -z \\ 0 & 1 & 0 & 0 & 0 & z & -y & -ct & 0 & 0 \\ 0 & 0 & 1 & 0 & -z & 0 & x & 0 & -ct & 0 \\ 0 & 0 & 0 & 1 & y & -x & 0 & 0 & 0 & -ct \\ 0 & 0 & -z & y & y^2+z^2 & -xy & -zx & 0 & ctz & -cty \\ 0 & z & 0 & -x & -xy & z^2+x^2 & -yz & -ctz & 0 & ctx \\ 0 & -y & x & 0 & -zx & -yz & x^2+y^2 & cty & -ctx & 0 \\ -x & -ct & 0 & 0 & 0 & -ctz & cty & c^2t^2-x^2 & -xy & -zx \\ -y & 0 & -ct & 0 & ctz & 0 & -ctx & -xy & c^2t^2-y^2 & -yz \\ -z & 0 & 0 & -ct & -cty & ctx & 0 & -zx & -yz & c^2t^2-z^2 \end{bmatrix}$$



$$c = 299{,}792{,}458\ \mathrm{m \cdot s^{-1}}$$
$$h = 6.62607015 \times 10^{-34}\ \mathrm{J \cdot s}$$
$$e = 1.60217663 \times 10^{-19}\ \mathrm{C}$$
$$m_e = 9.1093837 \times 10^{-31}\ \mathrm{kg}$$
$$k_B = 1.380649 \times 10^{-23}\ \mathrm{J \cdot K^{-1}}$$
$$R = 8.3144626\ \mathrm{J \cdot K^{-1} \cdot mol^{-1}}$$
$$N_A = 6.02214076 \times 10^{23}\ \mathrm{mol^{-1}}$$

Design Goals for Radical Pie

- 100% graphical interface with full feature discoverability

- Highest possible output quality
  - Always matching or exceeding LaTeX

- Robust copy/paste to other applications
- Robust save to SVG / PDF formats
- Seamless integration with Microsoft Word
- Deep customizability

Radical Pie Timeline

- Proof of concept begun September 4, 2024.
- Full-time development begun in December 2024.
- Version 1.0 released October 27, 2025.
- Now on version 1.12, as of July 2026.

Code Stats

• New application-specific code	110 kLOC	43 source files, light comments
• Math / container libraries	45 kLOC	78 source files, heavy comments
• Slug library	39 kLOC	14 source files, light comments
• Total	194 kLOC	

• Builds in 7.0 sec in Visual Studio on 12-core CPU

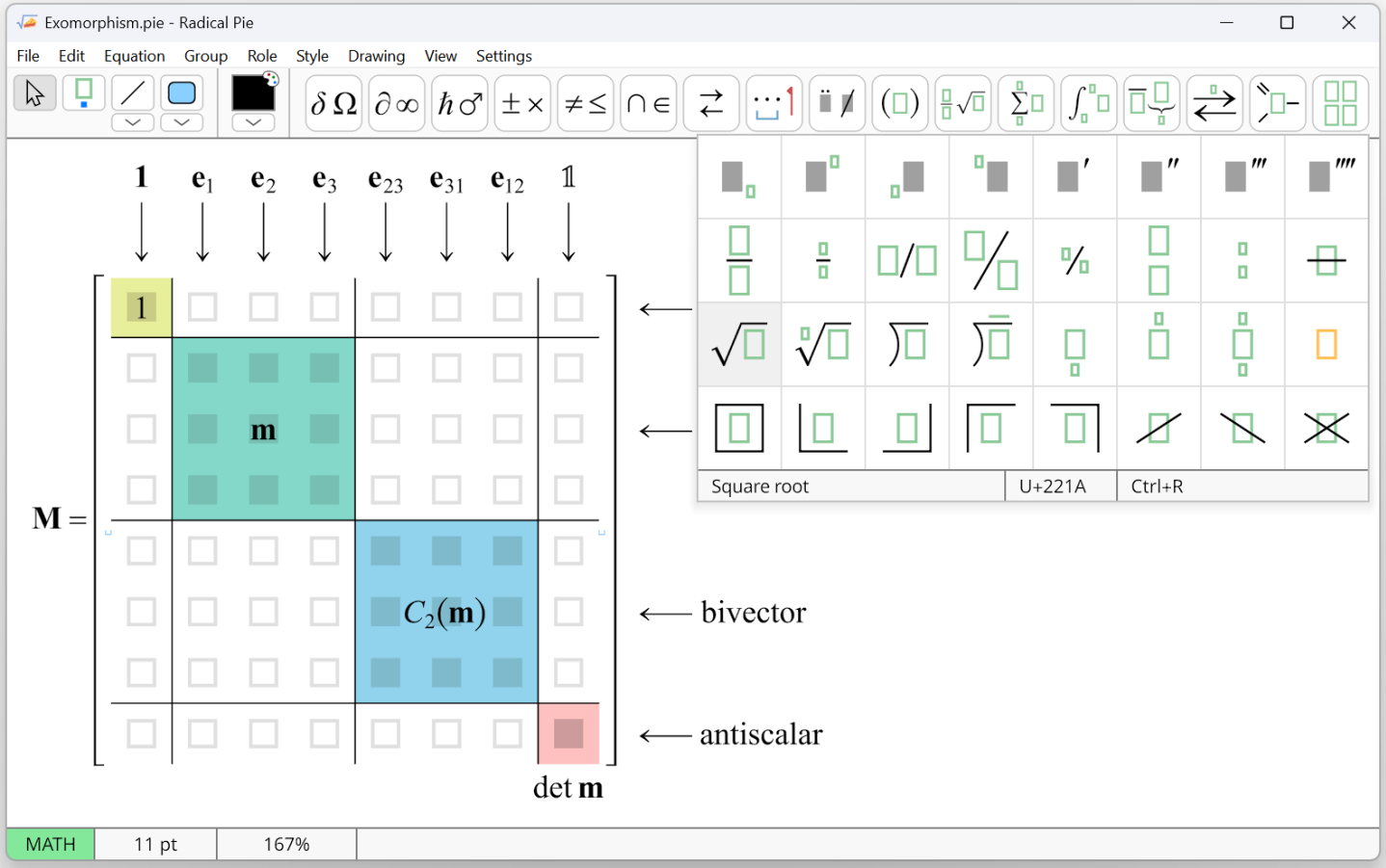
Basics

- 100% C++ “lite”
  - No standard library
  - No exceptions / RTTI
- Interfaces directly with minimal Win32 API surface
  - Window creation / message pump
  - Menu handling / accelerators
  - COM / OLE for Microsoft Word interop
- D3D11 render target / swap chain for all window contents

Exhaustive List of External Dependencies

Window Contents

- All contents rendered as vector graphics on the GPU

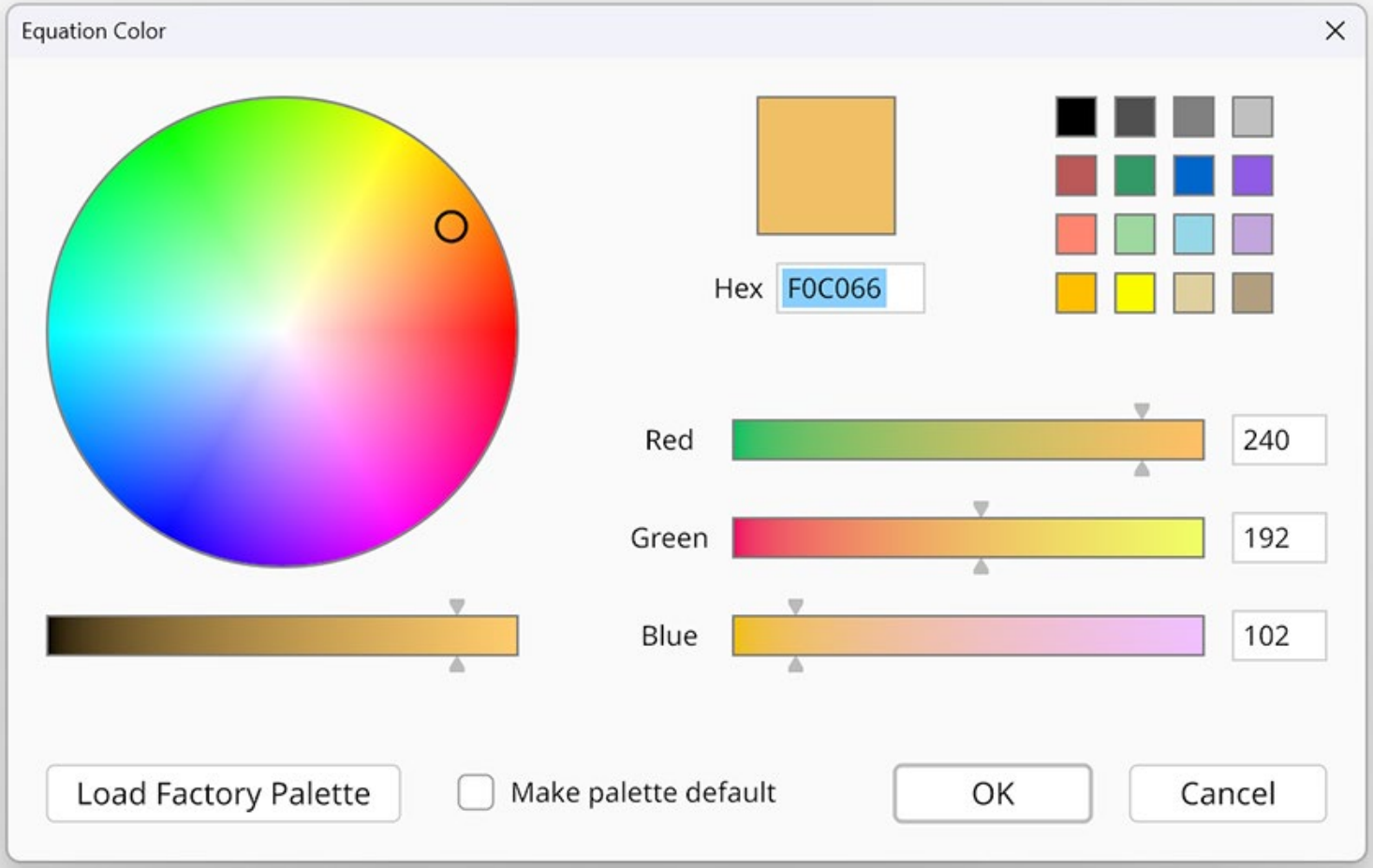


Dialog Boxes

- Dialogs get their own swap chains
- Radical Pie contains its own custom widget library
- All widgets rendered as vector graphics on GPU
- Avoids bloat of OS UI libraries, keeps DLL dependencies low
- Will make porting to other platforms much easier

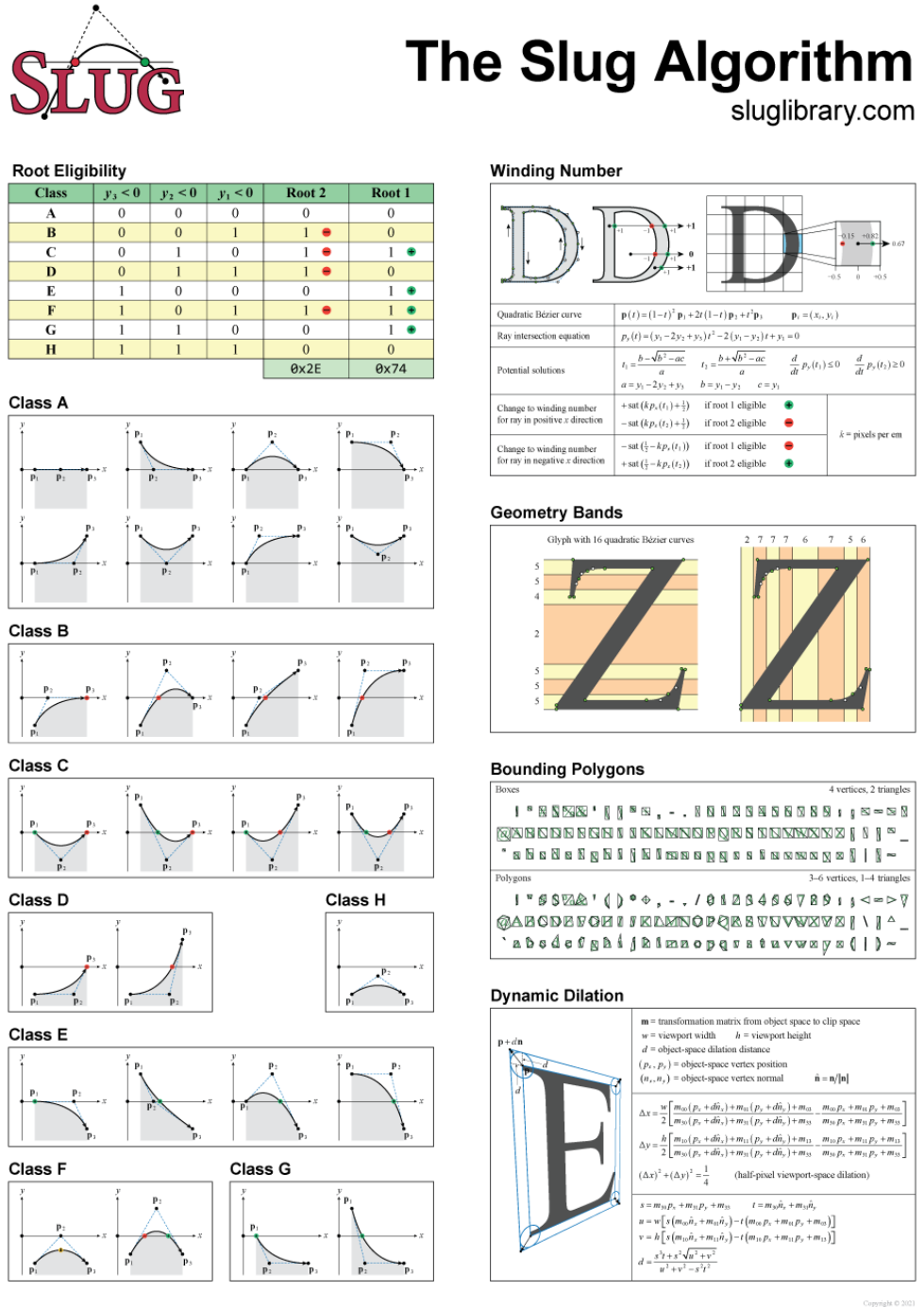
Widgets

- Static text
- Editable text
- Pushbutton
- Scroll bar
- Check box
- Color box
- List box
- Slider
- Line, rect, fill, ...



Slug Library

- State-of-the-art font rendering
- Also renders vector graphics
- Handles all rendering in RP
- Responsible for parsing TrueType / OpenType fonts
- `slugfont` tool runs as separate process to import font data

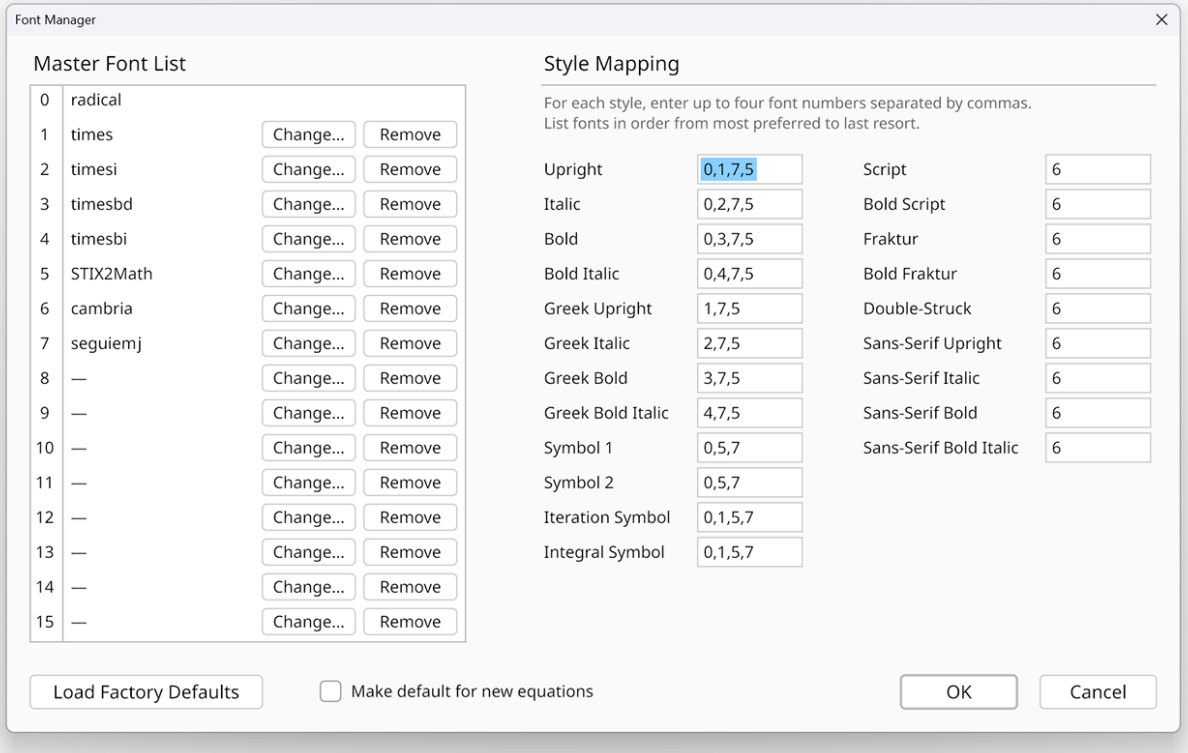


Slug Library

- Essential core technology already complete and mature
- Slug Library is statically integrated into application
  - Has no dependencies whatsoever
  - Doesn’t even allocate memory
- I estimate it would have taken two additional years to make Radical Pie if Slug had not already existed

Font Handling

- Radical Pie makes use of Slug's font mapping features
- Multiple fonts from a master list can be specified for each style



Nontextual Pieces of an Equation

- Stretchy parentheses, brackets, braces, etc.
- Wide marks above / below expression
- Radicals, quotients, fraction bars, boxes, strikeouts
- Arrows, chemical bonds
- Integrals

- Radical Pie generates new Bézier curves for these as needed
- Overlapping pieces in technical fonts not used at all

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad \begin{Bmatrix} x \\ y \\ z \end{Bmatrix} \quad \left\langle \begin{matrix} x \\ y \\ z \end{matrix} \right\rangle \quad \left\langle\!\left\langle \begin{matrix} x \\ y \\ z \end{matrix} \right\rangle\!\right\rangle \quad \left[\!\left[\begin{matrix} x \\ y \\ z \end{matrix} \right]\!\right] \quad \begin{vmatrix} x \\ y \\ z \end{vmatrix} \quad \begin{Vmatrix} x \\ y \\ z \end{Vmatrix}$$

$$\sqrt{a^2 + b^2} \qquad \sqrt{\frac{m_x^2 + m_y^2 + m_z^2}{v_x^2 + v_y^2 + v_z^2}}$$

$$\overline{abcde} \quad \overline{\overline{abcde}} \quad \overparen{abcde} \quad \overparen{abcde} \quad \overbrace{abcde} \quad \overbrace{abcde} \quad \overbrace{abcde} \quad \overbracket{abcde} \quad \overbrace{abcde}$$

$$\underline{abcde} \quad \underline{\underline{abcde}} \quad \underparen{abcde} \quad \underparen{abcde} \quad \underbrace{abcde} \quad \underbrace{abcde} \quad \underbrace{abcde} \quad \underbracket{abcde} \quad \underbrace{abcde}$$

$$\overleftarrow{abcde} \quad \overrightarrow{abcde} \quad \overleftrightarrow{abcde} \quad \overleftarrow{abcde} \quad \overrightarrow{abcde} \quad \overleftrightarrow{abcde} \quad \overleftarrow{abcde} \quad \overrightarrow{abcde} \quad \overleftrightarrow{abcde}$$

$$\underleftarrow{abcde} \quad \underrightarrow{abcde} \quad \underleftrightarrow{abcde} \quad \underleftarrow{abcde} \quad \underrightarrow{abcde} \quad \underleftrightarrow{abcde} \quad \underleftarrow{abcde} \quad \underrightarrow{abcde} \quad \underleftrightarrow{abcde}$$

$$\int_a^b f(x)\,dx \qquad \int_a^b \frac{f(x)}{g(x)}\,dx \qquad G \xrightarrow{f_{\mathrm{abc}}(x)} H \qquad 8\overline{)65536} = 8192 \qquad \boxed{a + b + c + d}$$

Robust Copy / Paste

- Need to have reliable copy / paste into other applications
  - PowerPoint slides
  - Illustrator diagrams
  - Video editors

- Most applications have serious problems with fonts, spacing, alignment, etc.

- Equation stored on clipboard in EMF and SVG formats

Robust Copy / Paste

- Radical Pie outlines everything so copied graphics are just a list of filled paths with solid colors
- Convenient when equations moved to another machine that may not have original fonts installed
- Word documents containing Radical Pie equations still display and print correctly without original fonts

Copy / Paste Example

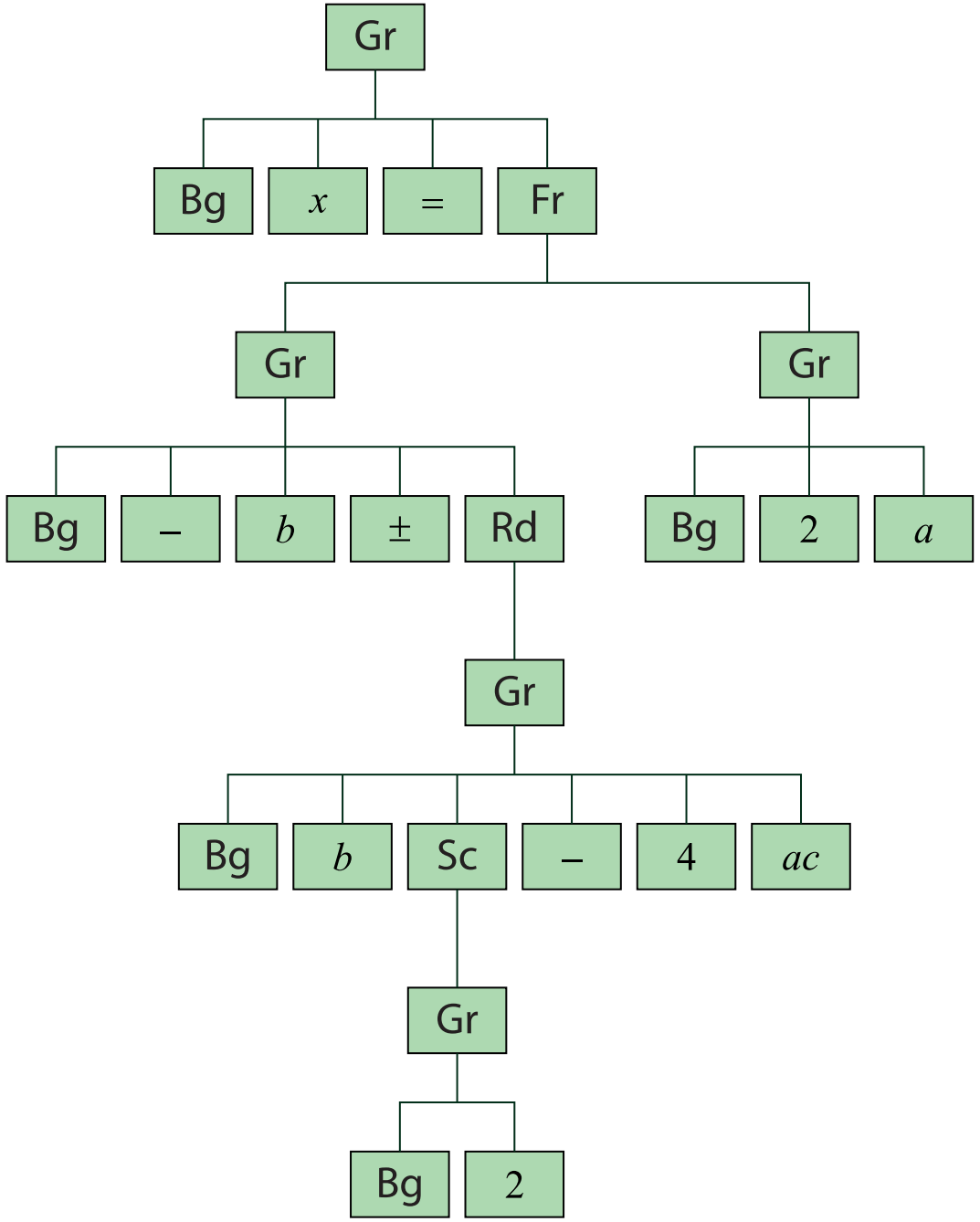
	Radical Pie	MathType	LaTeX (MathJax)	Office
Original	$\widetilde{abcde}$ $\underset{\sim}{abcde}$	$\widetilde{abcde}$ not available	$\widetilde{abcde}$ not available	$\widetilde{abcde}$ not available
Copy/paste into Illustrator	$\widetilde{abcde}$	⊠$abcde$	abcde˜⊠	$a\ \wr\ c\ a\ e$

Equation Structure

- Equations naturally form trees

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

- Tree is a collection of nodes
- Each node has list of subnodes



Equation Node Types

- Al Aligner
- Ar Arrow
- Bd Bond
- Bg Begin
- Br Bracket
- Bx Box
- Dv Division
- En Enclose
- Fr Fraction
- Gr Group
- In Integral
- It Iteration
- Kt Strike
- Mk Mark
- Mx Matrix
- Ng Negate
- Ph Phantom
- Pr Prime
- Rd Radical
- Sb Symbol
- Sc Script
- Sl Slash
- Sp Space
- St Stack
- Wm Widemark

Laying Out an Equation

- Equation tree is traversed
- Subnodes processed before parents
- Parent nodes know how large subnodes are
- Parent nodes determine positions of subnodes
- Lots of special processing going on

Laying Out an Equation

- Example: Iteration has up to 3 subgroups
  - Summand itself
  - Lower limit
  - Upper limit

- Must know sizes of limits before you know where to put summand

$$\sum_{k=1}^{\infty} a_k$$

Role and Style

- A “symbol” is the smallest piece of an equation
  - A variable or function
  - An operator or relation
  - A literal number
  - A text label

- Every symbol has a *role* and a *style*

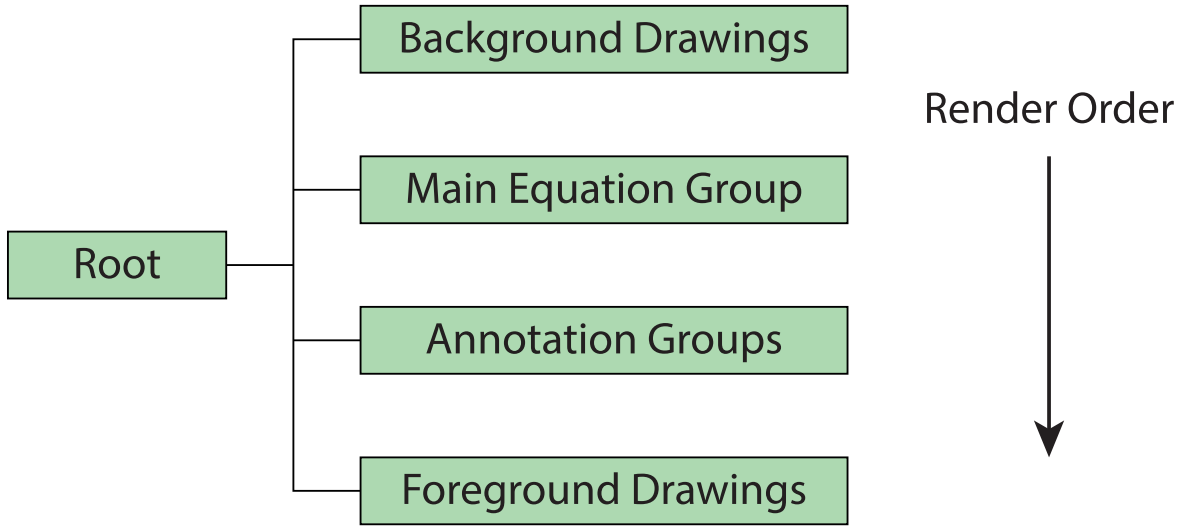
- One symbol can consist of several adjacent characters having the same role and style

Role and Style

- The style determines how a symbol *appears*
  - Upright, italic, bold, double-struck, script, fraktur, etc.
  - Selects font mapping
- The role determines how a symbol *behaves*
  - Mathematical name, chemical element, physical units
  - Operator, relation, number, arrow, bond, etc.
  - Affects spacing
- Style also determines whether italic corrections are applied

Drawing Objects and Annotations

- Drawing objects and annotations reside at top level of tree
- Drawing objects can be in background or foreground



Drawing Objects and Annotations

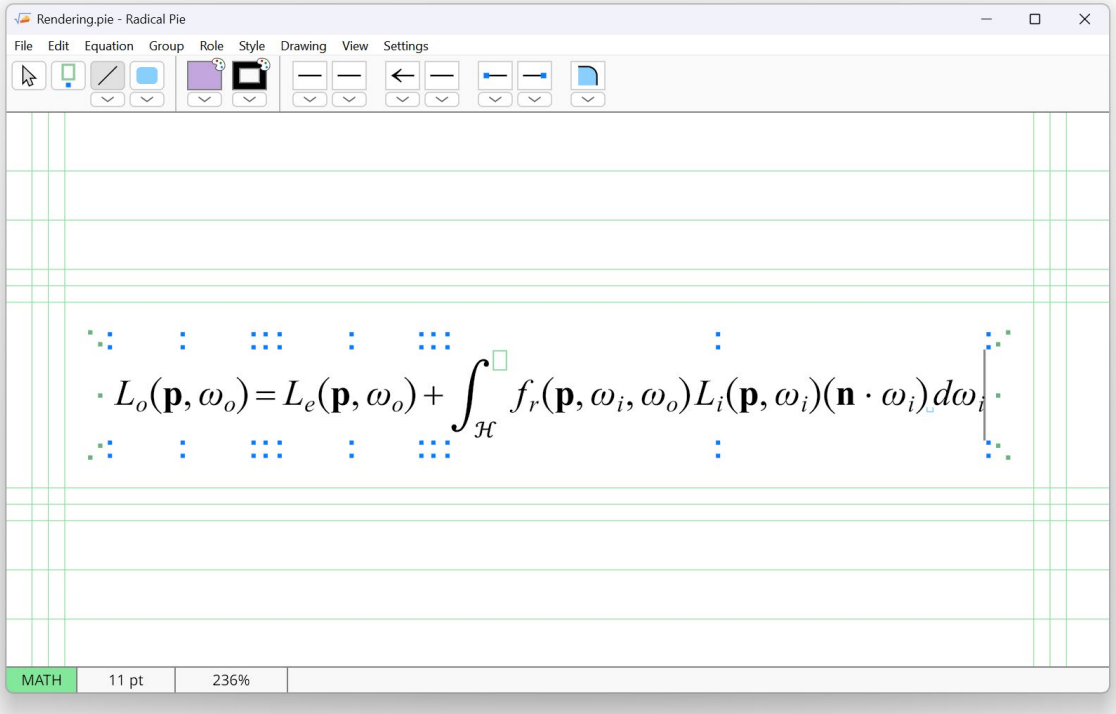
- Equation nodes, drawing objects, and annotations all have anchors of various types
- Top-level groups have special anchors called “rails”
- All drawing objects are attached to two anchors
- All annotations are attached to one anchor

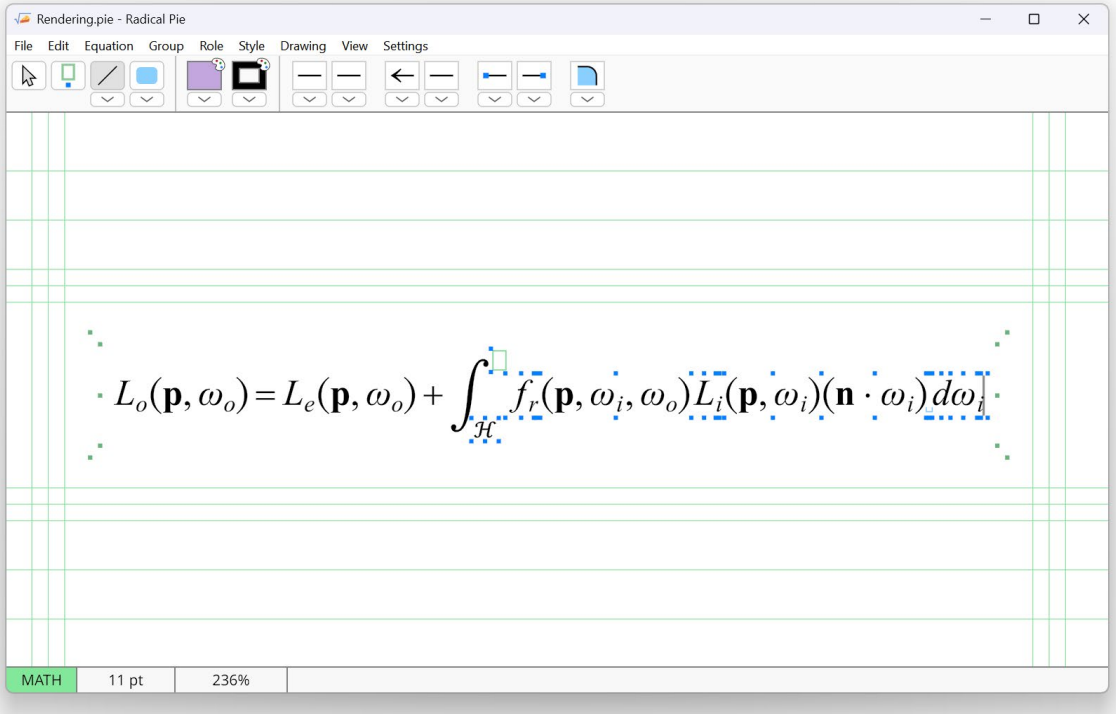
Anchors

- Anchors appear when drawing tool active
- Too many anchors in entire equation to show all at once
- Subset is displayed depending on what group contains caret

Anchors

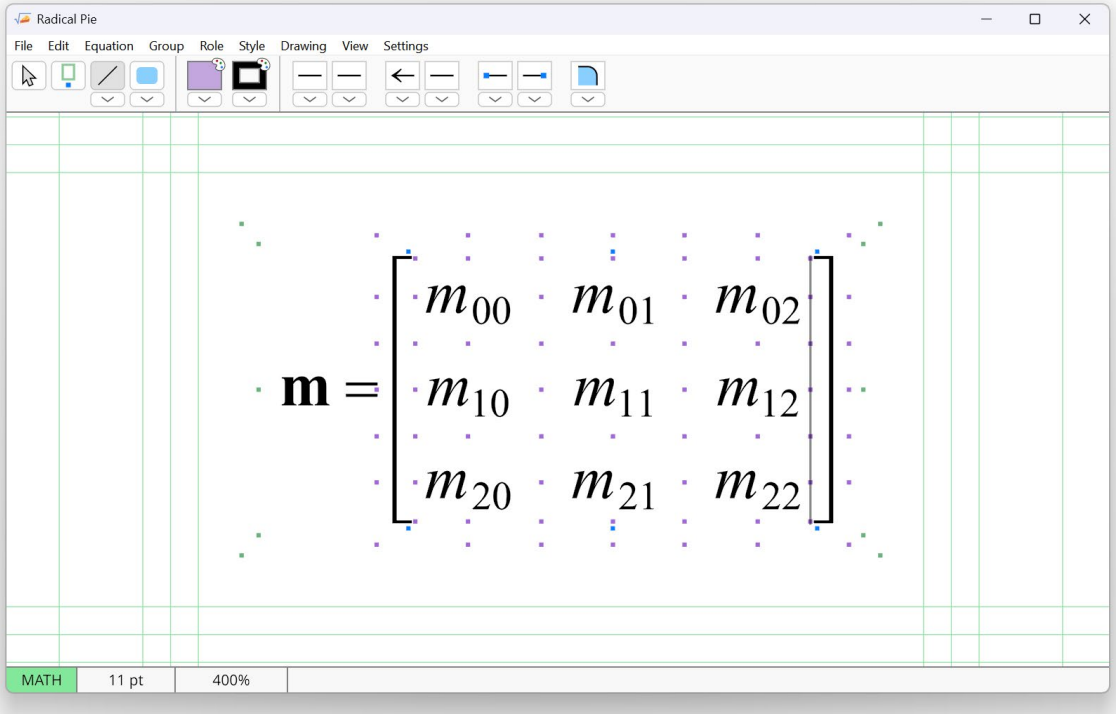
- Displayed anchors depend on what group contains caret

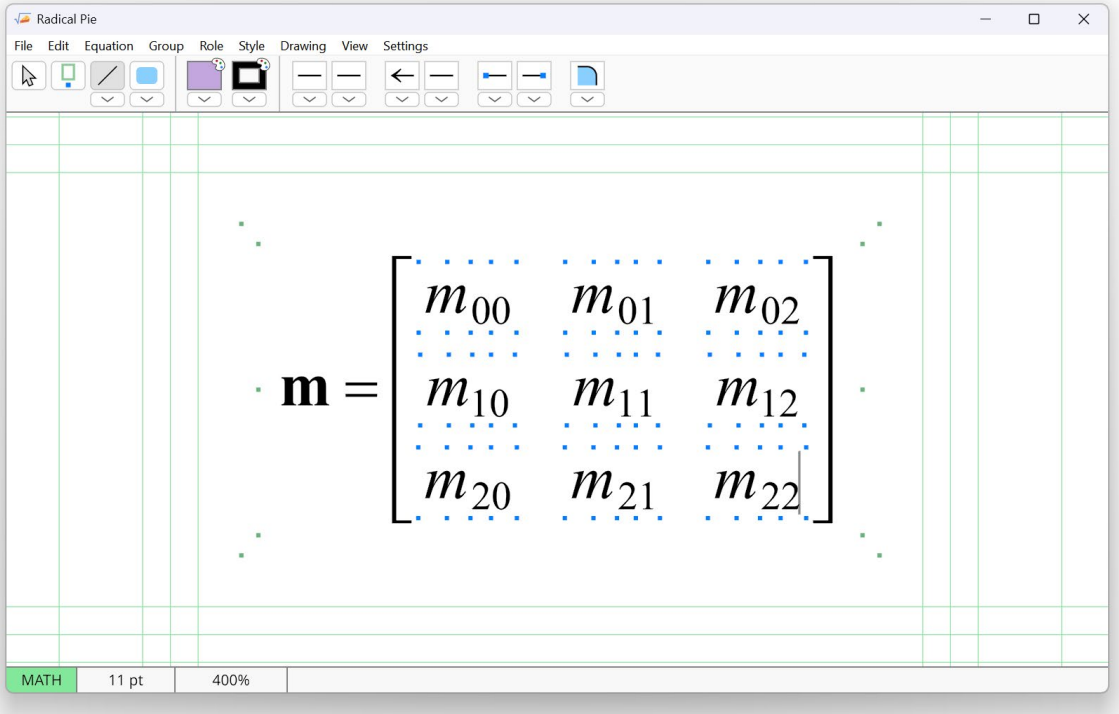




Anchors

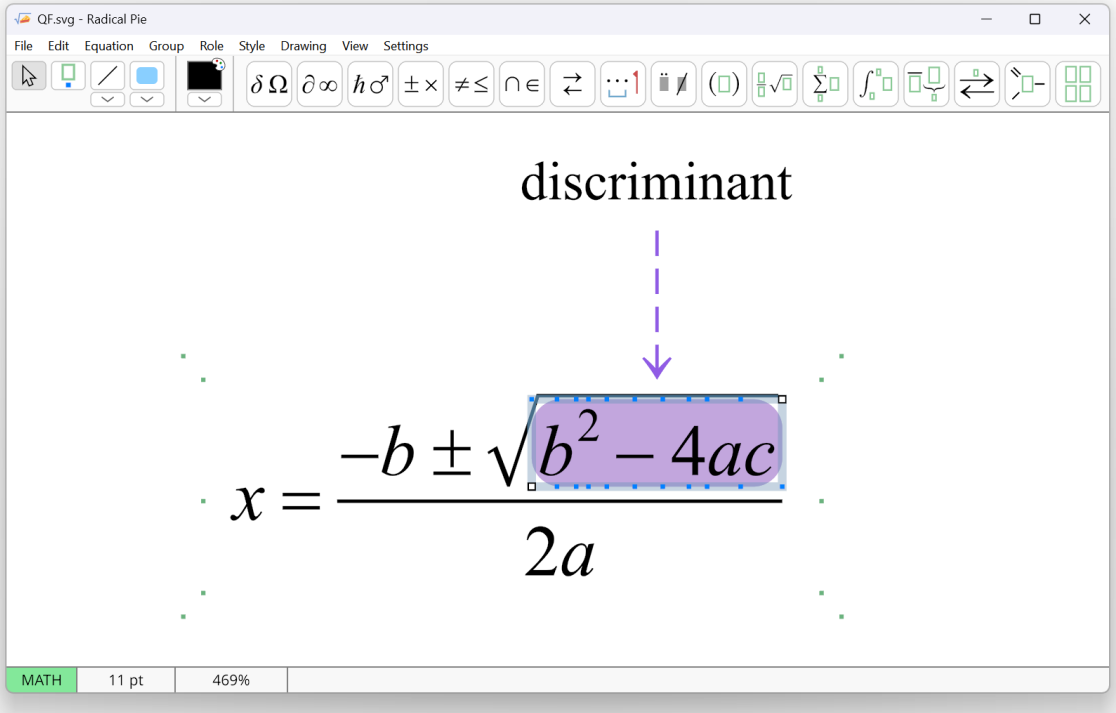
- Matrices advertise many more anchors

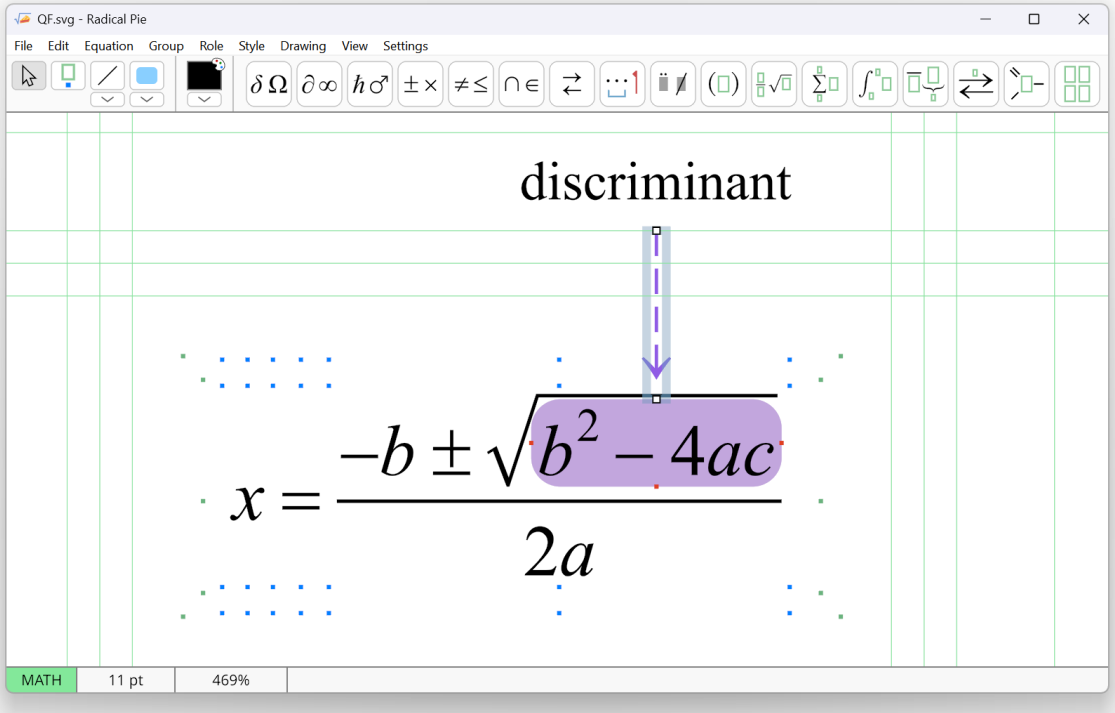




Node Graph

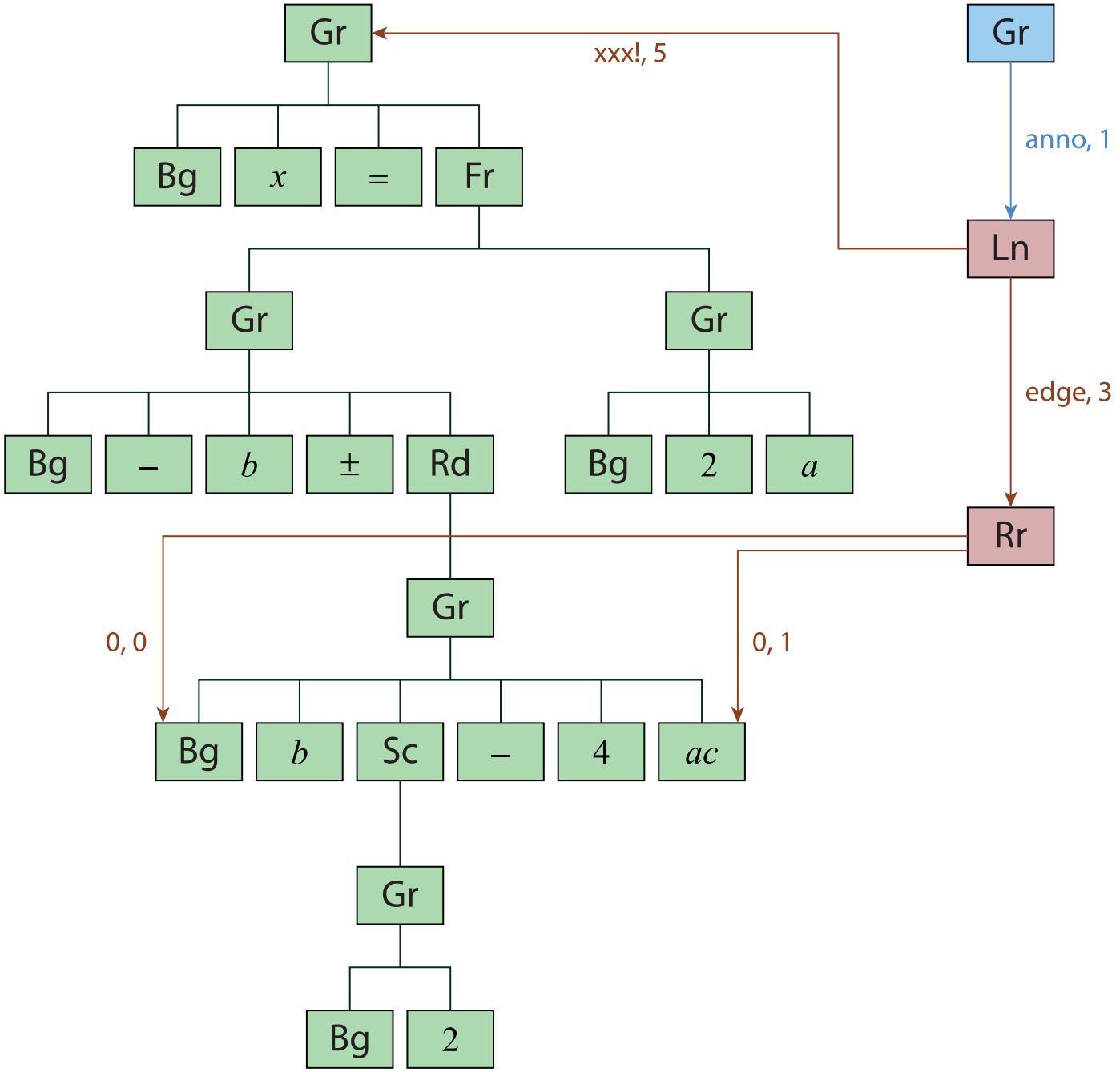
- Connections among drawings, annotations, and equation nodes constitute a *directed graph*





Node Graph

- Relations in graph called “connectors”
- Each carries anchor type and index in node it connects to



Tree and Graph

- Every node belongs to the tree
- Some nodes will belong to the graph as well
- Special intrusive base classes handle each of these
- Graph relations have lightweight `Connector` class

Node Deletion

- When a node is deleted, the base classes automatically remove it from the tree and the graph
- Any connectors attached to the node are deleted
- We don’t want disconnected nodes in the graph
  - Drawing objects and annotations always have to be attached to something in an equation

Node Deletion

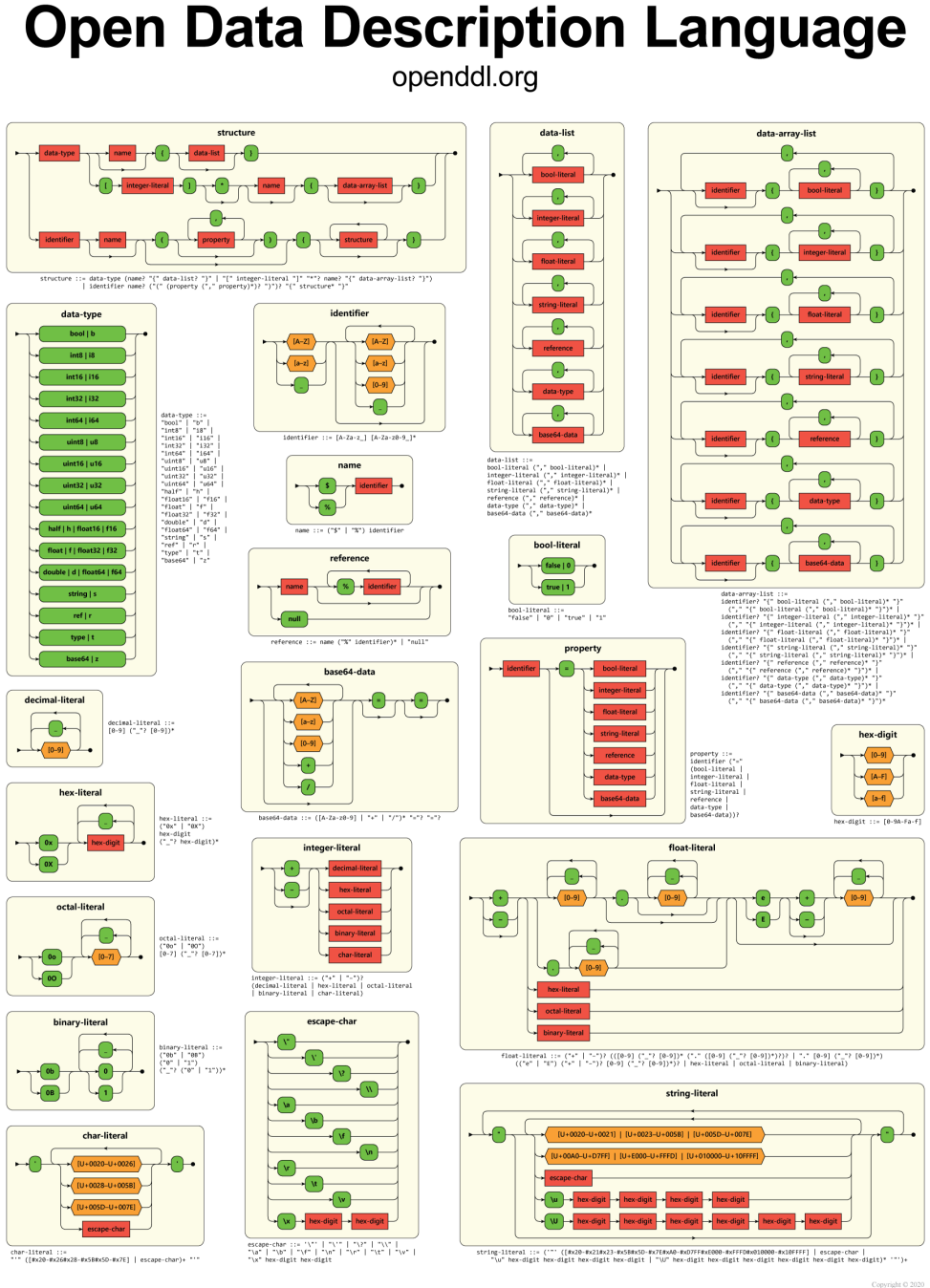
- Before base class destructors run, we iterate through all incoming connectors and delete the node on the other end
- We must be careful when doing this because deleting a node can auto-delete any number of incoming connectors
- Solution is to collect all the incoming connectors in a list first, and then keep deleting first connector in list until none left
- When connector is deleted, it auto-removes itself from list

Serialization Format

- Obviously, we need a way to save and reload equations
- Not only for saving files, but for storing undo / redo snapshots
- Format needs to capture tree and graph structures
- Preferably text-based to make embedding easy in other formats like SVG

OpenDDL

- General data description language
- Developed in 2013 for Open Game Engine Exchange format (OpenGEX)
- C-like syntax with braced arrays
  - Same int, FP, hex / binary syntax
  - Same escape characters
  - Same comments



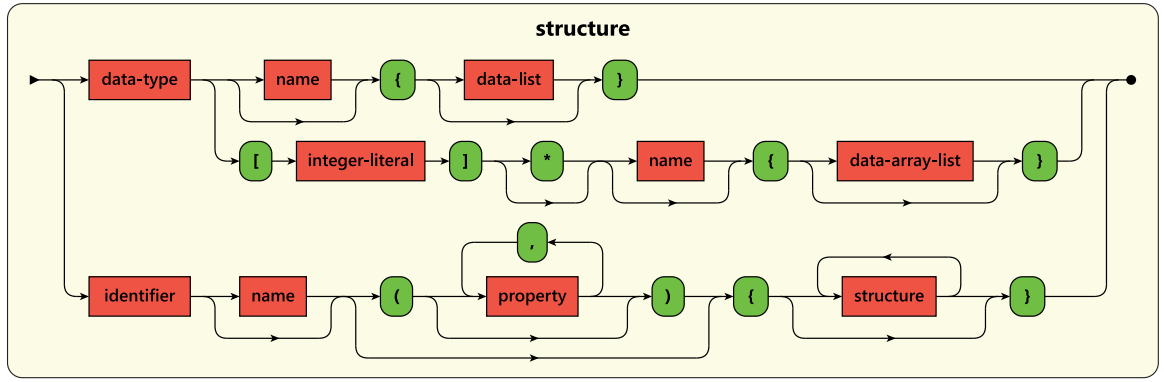
OpenDDL

- Strongly typed
  - b, bool (false, true or 0, 1)
  - i8, i16, i32, i64, int8, int16, int32, int64
  - u8, u16, u32, u64, uint8, uint16, uint32, uint64
  - h, f, d, half, float, double (or float16, float32, float64)
  - s, string (always UTF-8)
  - r, ref (links to other structures)
  - t, type (for schemas)
  - z, base64

- Parser enforces proper types for data elements

OpenDDL

- Application defines custom structures and provides validation functions for their relationships



- Structures form an implicit tree
- Custom structures can have properties, convenient for storing object states

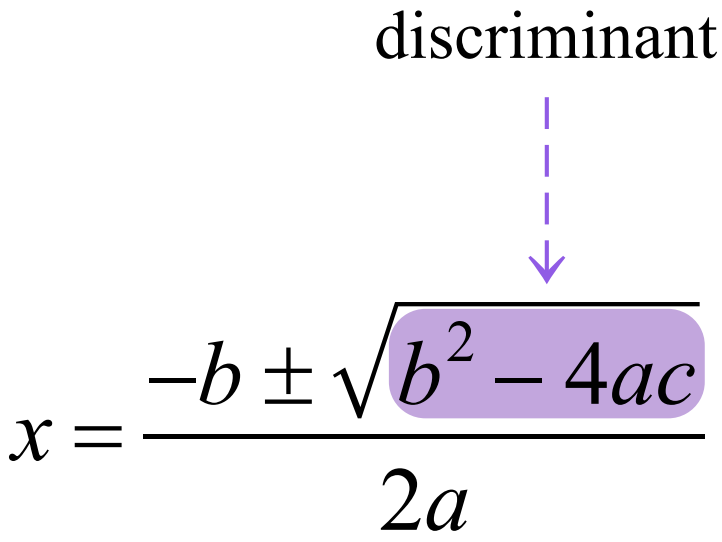
Serialized Equation

```
Gr
{
   Bg {}
   Sb {s{"x"}}
   Sb (ro='rltn') {s{"="}}
   Fr
   {
      Gr (t='numr')
      {
         Bg {}
         Sb (ro='oper') {s{"−"}}
         Sb {s{"b"}}
         Sb (ro='oper') {s{"±"}}
         Rd
         {
            Gr
            {
               Bg {}
               Sb {s{"b"}}
               Sc
               {
                  Gr (t='sups')
                  {
                     Bg {}
                     Sb (ro='nmbr') {s{"2"}}
                  }
               }
               Sb (ro='oper') {s{"−"}}
               Sb (ro='nmbr') {s{"4"}}
               Sb {s{"ac"}}
            }
         }
      }
      Gr (t='dnom')
      {
         Bg {}
         Sb (ro='nmbr') {s{"2"}}
         Sb {s{"a"}}
      }
   }
}
```

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Anchor References

```
Rr $_0 (f,fpi=11,r=1)
{
   X
   {
      ref{$_3,$_4}
      u32{0,0}
      i32{0,1}
   }
}
Ln $_1 (s,d=2,spi=7,es='arr2',os='shrt')
{
   X
   {
      ref{$_0,$_2}
      u32{'edge','xxx!'}
      i32{3,5}
   }
}
Gr $_2
{
   Bg {}
   Sb {s{"x"}}
   Sb (ro='rltn') {s{"="}}
   Fr
   {
      Gr (t='numr')
      {
         Bg {}
         Sb (ro='oper') {s{"−"}}
         Sb {s{"b"}}
         Sb (ro='oper') {s{"±"}}
         Rd
         {
            Gr
            {
               Bg $_3 {}
               Sb {s{"b"}}
               Sc
               {
                  Gr (t='sups')
                  {
                     Bg {}
                     Sb (ro='nmbr') {s{"2"}}
                  }
               }
               Sb (ro='oper') {s{"−"}}
               Sb (ro='nmbr') {s{"4"}}
               Sb $_4 {s{"ac"}}
            }
         }
      }
      Gr (t='dnom')
      {
         Bg {}
         Sb (ro='nmbr') {s{"2"}}
         Sb {s{"a"}}
      }
   }
}
Gr (as=0.75,t='anno',al='cent')
{
   Bg {}
   Sb (ro='text') {s{"discriminant"}}
   X
   {
      ref{$_1}
      u32{'anno'}
      i32{1}
   }
}
```



Embedding

- Native .pie file just contains OpenDDL
- Same OpenDDL text is embedded in SVG, PDF, and EMF formats as special comment
- Those comments are extracted when user opens SVG, PDF, or EMF file, restoring a fully-editable equation

SVG Format

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   Sb {s{"x"}}
   Sb (ro='rltn') {s{"="}}
   Fr
   {
      Gr (t='numr')
      {
         Bg {}
         Sb (ro='oper') {s{"--"}}
         Sb (s{"b"}}
         Sb (ro='oper') {s{"±"}}
         Rd
         {
            Gr
            {
               Bg {}
               Sb {s{"b"}}
               Sc
               {
                  Gr (t='sups')
                  {
                     Bg {}
                     Sb (ro='nmbr') {s{"2"}}
                  }
               }
               Sb (ro='oper') {s{"--"}}
               Sb (ro='nmbr') {s{"4"}}
               Sb {s{"ac"}}
            }
         }
      }
      Gr (t='dnom')
      {
         Bg {}
         Sb (ro='nmbr') {s{"2"}}
         Sb {s{"a"}}
      }
   }
}
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   Q54.0802307,8.0306987,54.1446838,8.0306987 Q54.214508,8.0306987,54.327301,7.9447612 Q54.5367736,7.7889995,54.8858947,7.30023 Q55.0685119,7.4291362,55.0685119,7.4291362 Q54.6979064,7.98773,54.3058166,8.2804546
   Q53.9137268,8.5731792,53.5807189,8.5731792 Q53.3497619,8.5731792,53.2342834,8.4577007 Q53.1188049,8.3422222,53.1188049,8.1220073 Q53.1188049,7.8588237,53.2369689,7.4291362 Q53.3497619,7.0263042,53.3497619,7.0263042
   Q52.6461486,7.9447612,52.0553283,8.3099956 Q51.6310119,8.5731792,51.2228088,8.5731792 Q50.8307189,8.5731792,50.546051,8.248228 Q50.261383,7.9232769,50.261383,7.3539409 Q50.261383,6.499937,50.7743225,5.551939
   Q51.2872619,4.6039409,52.0768127,4.034605 Q52.6944885,3.5834331,53.24234,3.5834331 Q53.5699768,3.5834331,53.7875061,3.7553081 Q54.0050354,3.9271831,54.1178283,4.324644 Q54.3111877,3.7123394,54.3111877,3.7123394
   Q55.1651916,3.5834331,55.1651916,3.5834331 Z M53.2530822,3.86273 Q52.9093322,3.86273,52.5226135,4.1849956 Q51.9747619,4.6415386,51.54776,5.5385112 Q51.120758,6.4354839,51.120758,7.1605815 Q51.120758,7.5258159,51.3033752,7.7379741
   Q51.4859924,7.9501323,51.7223205,7.9501323 Q52.3077697,7.9501323,52.9952697,7.0853862 Q53.9137268,5.9359722,53.9137268,4.7274761 Q53.9137268,4.2709331,53.7364807,4.0668315 Q53.5592346,3.86273,53.2530822,3.86273 Z"/>
</svg>
```

OpenDDL comment

List of filled paths

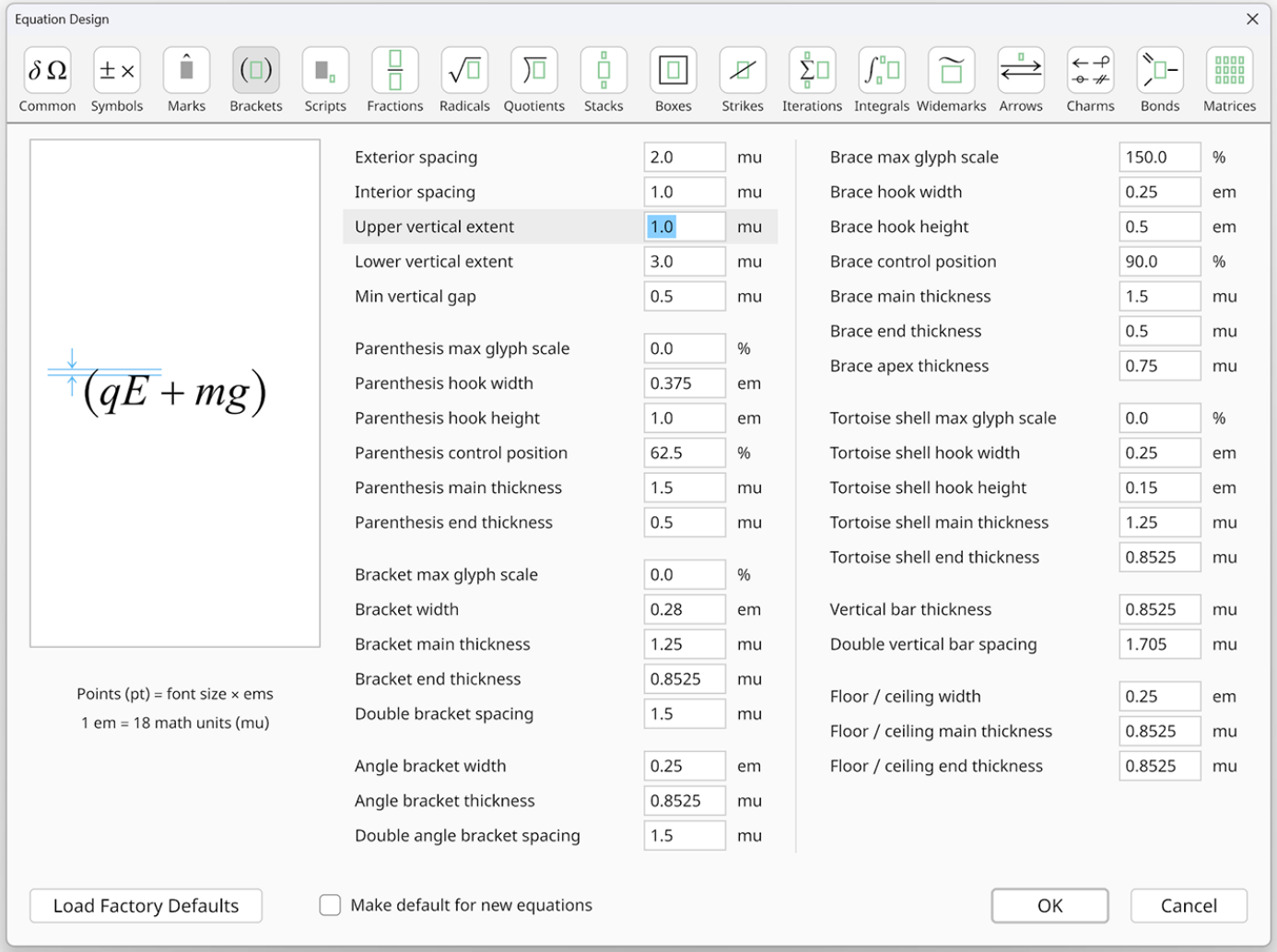
Undo / Redo

- Snapshot of entire equation taken twice for every action
  - Undo snapshot before, and redo snapshot after
  - Extra information about current selection and editor mode also saved
- Serialized to OpenDDL string in memory, stored in list
- Consecutive symbols with same role and style are coalesced by replacing most recent snapshot
- Undo just destroys current equation entirely and deserializes the previous snapshot

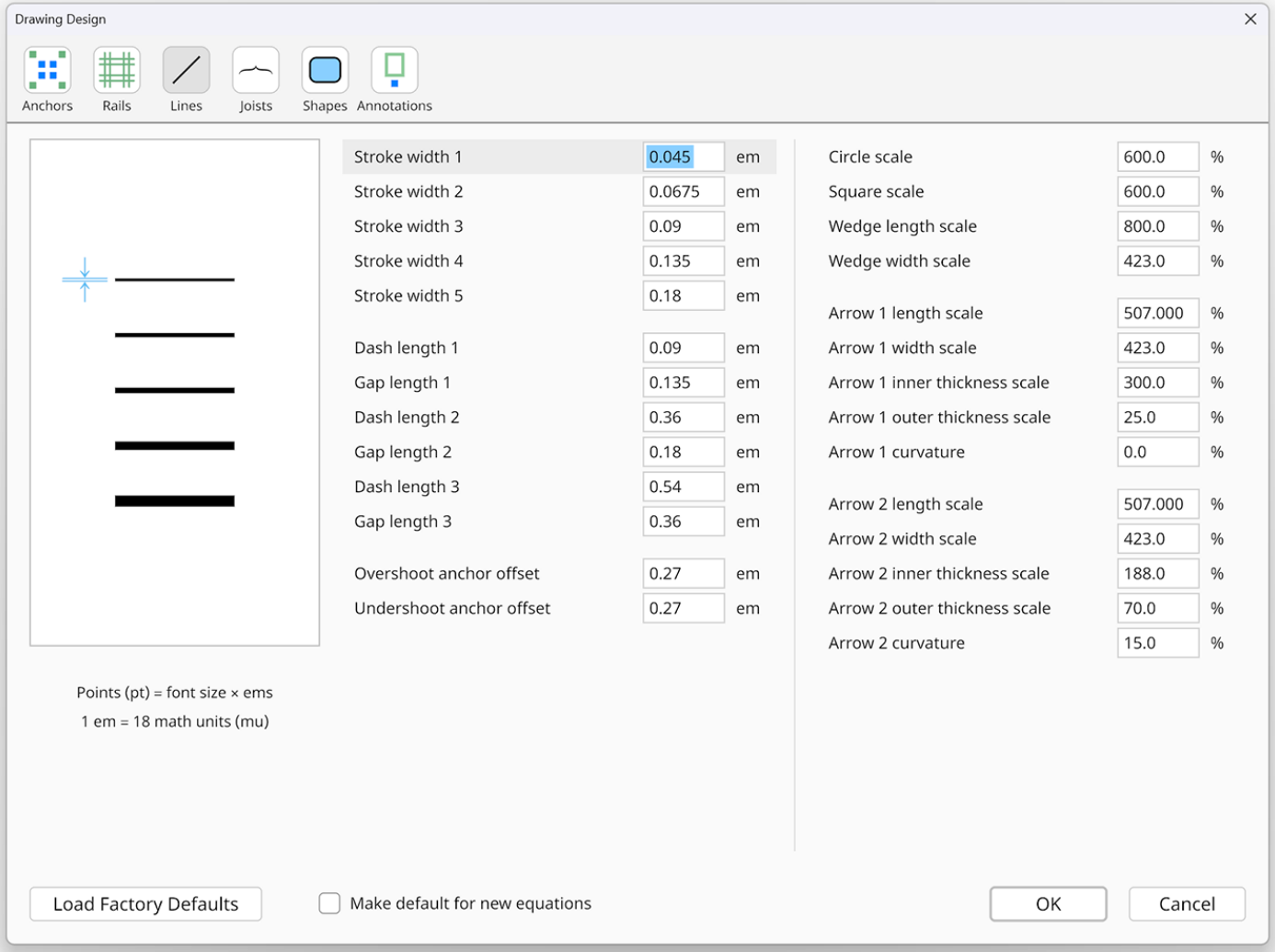
Customization

- Radical Pie provides 374 configurable parameters that control equation appearance
  - Lots of spacing
  - Rule thicknesses
  - Bracket / brace shapes
  - Arrow shapes
  - Integral lean angle
  - Anchor positioning
  - ...

Equation Design

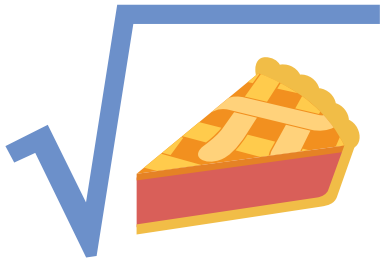


Drawing Design



Design Parameters

- Each design parameter is identified by domain and type
- Non-factory values are stored with equation in special design structure
- User can save default design
  - OpenDDL containing only design params saved in `AppData` folder



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