

Software Design in the Radical Pie Equation Editor

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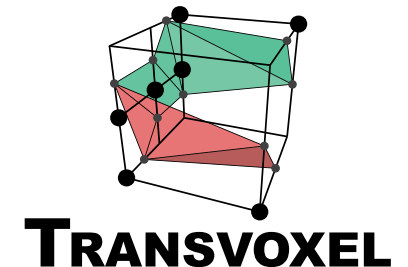
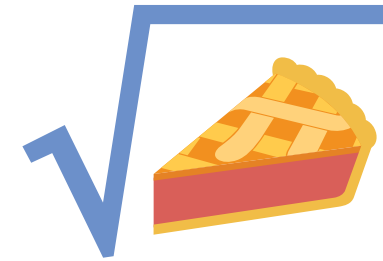
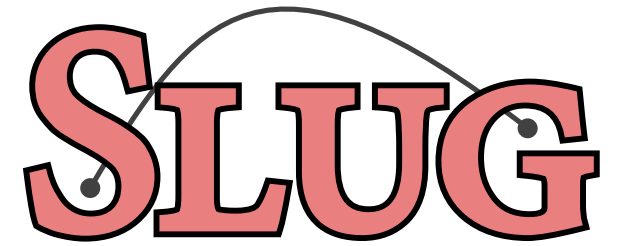
Better Software Conference 2026

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

Mathematicians love mathematics,
and computer scientists hate computers.

About the Speaker

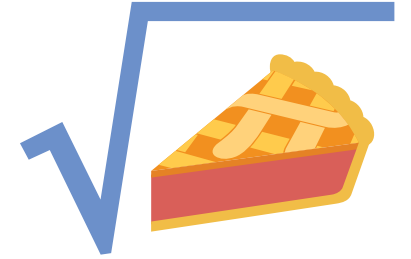
- Working in industry since 1994
- Former Sierra, Apple, Naughty Dog
- Running own business since 2005
 - C4 Engine
 - Slug Library
 - Radical Pie
- Writes books, occasionally teaches



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

The image shows a screenshot of the 'Radical Pie' software editor window. The window has a title bar with the name 'Radical Pie' and standard window controls. Below the title bar is a menu bar with options: File, Edit, Equation, Group, Role, Style, Drawing, View, and Settings. Underneath the menu bar is a toolbar containing various mathematical symbols and icons, such as δ , Ω , ∂ , ∞ , h , σ , $\pm$, $\times$, $\neq$, $\leq$, $\cap$, $\in$, $\rightleftharpoons$, $\dots$, $\frac{1}{x}$, $\frac{d}{dx}$, $()$, $\sqrt{}$, $\sum$, $\int$, $\frac{\partial}{\partial x}$, $\Leftrightarrow$, and a grid icon. The main editing area displays the quadratic formula:
$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$
 The term $b^2 - 4ac$ under the square root is highlighted with a light blue background. At the bottom of the window is a status bar with three sections: 'MATH' (highlighted in green), '11 pt', and '600%'. There is also an empty section on the right side of the status bar.

17 Symbol / Structure Palettes

α	β	γ	δ	ε	ζ	η	θ
ι	κ	λ	μ	ν	ξ	o	π
ρ	σ	τ	υ	φ	χ	ψ	ω
ϱ	ς	ϕ	κ	ϕ	ϑ	ϵ	ϖ
Γ	Δ	Θ	Λ	Ξ	Π	Σ	Φ
Ψ	Ω	Θ	F	Υ			
Alpha				U+03B1	Ctrl+G → A		

∂	∇	Δ	$\square$	∞	$\aleph$	$\wp$	$\blacksquare$
$\parallel$	$\nmid$	$\perp$	$\angle$	$\triangleleft$	$\dagger$	$\ddagger$	
$ $	$\dagger$	$\propto$	$\flat$	$\sharp$	$\natural$	$\emptyset$	$\odot$
$\bullet$	$\blacksquare$	$\blacktriangle$	$\star$	$\circ$	$\square$	$\triangle$	$\star$
Partial derivative				U+2202	Ctrl+G → \$		

h	λ	$\text{\AA}$	μ	Ω	Υ	$^\circ$	$\oplus$
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Planck's constant over 2 π				U+210F			

$\pm$	$\mp$	$\div$	$\times$	$\cdot$	$\circ$	$\ast$	
$\times$	$\times$	$\oplus$	$\ominus$	$\otimes$	$\odot$	$\odot$	$\otimes$
$\diamond$	$\star$	$\boxplus$	$\boxminus$	$\boxtimes$	$\boxdot$	$\ddots$	$\ddots$
$\wedge$	$\vee$	$\wedge$	$\vee$	$\wedge$	$\vee$	$\lceil$	$\rfloor$
∇	$\exists$	$\nexists$	$\neg$	$\neg$	$\neg$	$\neg$	$\neg$
Plus-minus				U+00B1	Ctrl+Shift+=		

$\neq$	$\sim$	$\approx$	$\cong$	$\simeq$	$\nlessapprox$	$\nlessapprox$	$\nlessapprox$
$\leq$	$\geq$	$\ll$	$\gg$	$\equiv$	$\approx$	$\neq$	$\neq$
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Not equal				U+2260	Ctrl+=		

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$\subset$	$\supset$	$\subset$	$\supset$	$\subset$	$\supset$	$\subset$	$\supset$
Empty set				U+2205	Ctrl+G →)		

$\leftarrow$	$\rightarrow$	$\uparrow$	$\downarrow$	$\nearrow$	$\nwarrow$	$\swarrow$	$\searrow$
$\leftrightarrow$	$\Rightarrow$	$\Uparrow$	$\Downarrow$	$\Leftrightarrow$	$\Rrightarrow$	$\Uparrow$	$\Downarrow$
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Left arrow				U+2190	Ctrl+G → {		

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$\leftrightarrow$	$\Rightarrow$	$\Uparrow$	$\Downarrow$	$\Leftrightarrow$	$\Rrightarrow$	$\Uparrow$	$\Downarrow$
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Left arrow				U+2B60			

$\dots$	$\dots$	$\vdots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$	$\ddots$
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$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$
Insert space...				Ctrl+Alt+Space			

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$\dot{\square}$	$\dot{\square}$	$\dot{\square}$	$\dot{\square}$	$\dot{\square}$	$\dot{\square}$	$\dot{\square}$	$\dot{\square}$
Dot above				U+0307	Ctrl+Shift+1		

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Parentheses				U+0028	Ctrl+9		

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Subscript				Ctrl+L or _			

$\sum$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$
$\sum$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$
$\sum$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$
$\sum$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$
$\sum$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$	$\prod$
Sum				U+2211			

$\int$	$\int$	$\int$	$\int$	$\int$	$\int$	$\int$	$\int$
$\int$	$\int$	$\int$	$\int$	$\int$	$\int$	$\int$	$\int$
$\int$	$\int$	$\int$	$\int$	$\int$	$\int$	$\int$	$\int$
Integral				U+222B			

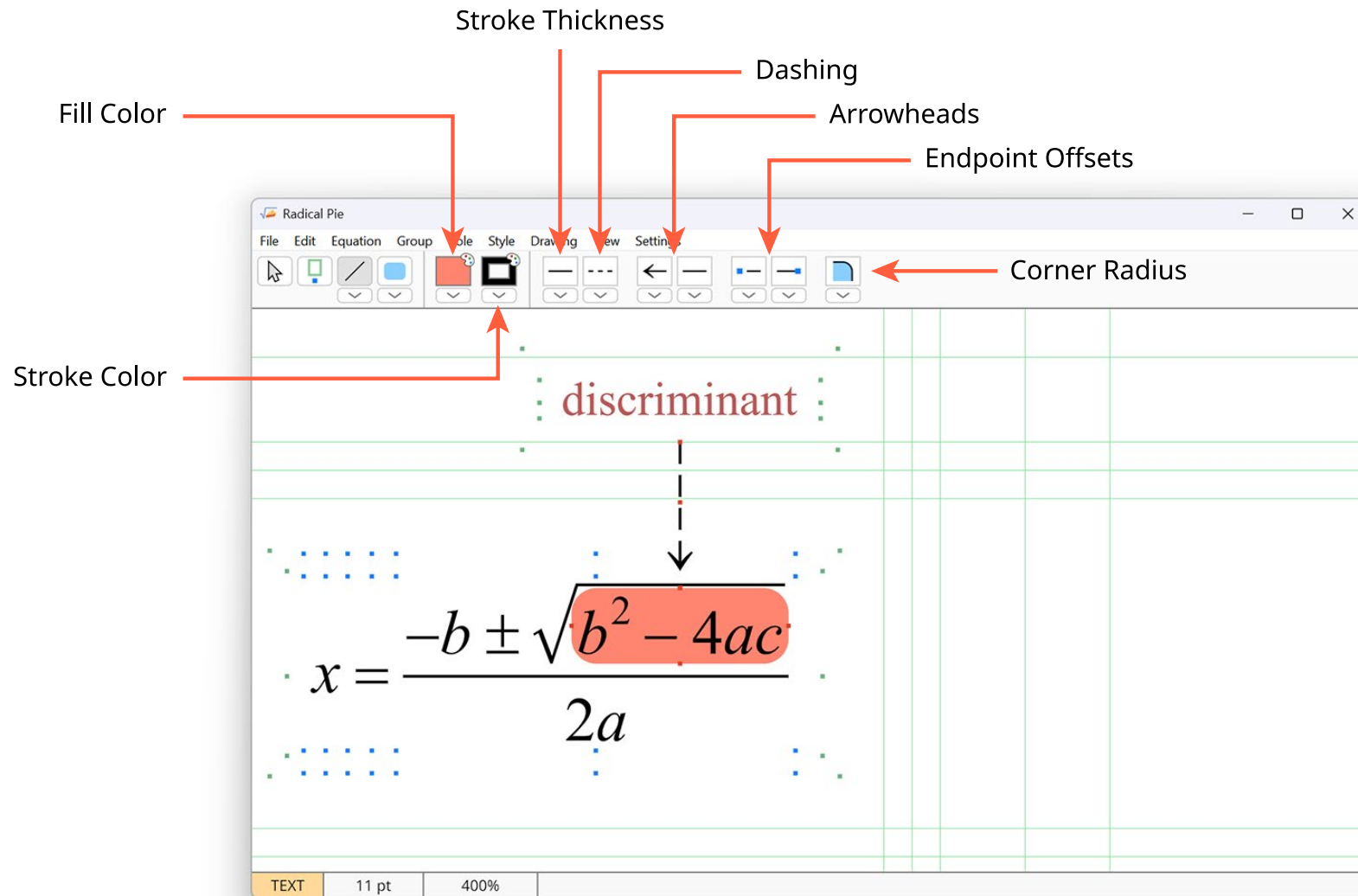
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Overline				Ctrl+-			

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$\rightarrow$	$\rightarrow$	$\rightarrow$	$\rightarrow$	$\rightarrow$	$\rightarrow$	$\rightarrow$	$\rightarrow$
Insert arrow...				Ctrl+Alt+A			

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Insert bond...				Ctrl+Alt+E			

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$\square$	$\square$	$\square$	$\square$	$\square$	$\square$	$\square$	$\square$
Insert matrix...				Ctrl+Alt+M			

Drawing and Annotation Tools



Properties Dialogs

Bracket Properties

☒ Left Symbol ☐ Center Symbol ☒ Right Symbol

Change... Change... Change...

Number of groups:

☐ Asymmetric vertical extent
☐ Center vertically on math axis

OK Cancel

Fraction Properties

Numerator alignment:   

Denominator alignment:   

☐ Use small layout
☒ Draw fraction bar
☐ Disable italic kerning

OK Cancel

Integral Properties

Integral Symbol 

Change...

☒ Include lower limit
☒ Include upper limit
☐ Use small layout
☐ Use inline limits
☐ Keep original glyph
☐ Grow integral size

OK Cancel

Script Properties

☒ Include subscript
☐ Include superscript
☐ Preceding script
☐ Align scripts outward
☐ Disable italic kerning

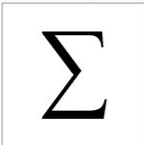
OK Cancel

Symbol Properties

☐ Use proportional figures
☐ Shift math axis for capitals
☐ Apply small caps substitution (if available)
☐ Apply capital punctuation forms (if available)
☐ Apply slashed zero alternate (if available)
☒ Enable accent mark italic shift
☒ Enable bold accent marks

OK Cancel

Iteration Properties

Iteration Symbol 

Change...

☒ Include lower limit
☒ Include upper limit
☐ Include modifier group
☐ Use small layout
☐ Use inline limits

OK Cancel

Arrow Builder

Insert Arrow

☒ Upper label [≡] [≡] [≡]

☒ Arrow 1 > — — — — — ○ — — — — — || → ☐ Short [≡] [≡] [≡]

☒ Arrow 2 ← ← — — — — — — — — — — ☒ Short [≡] [≡] [≡]

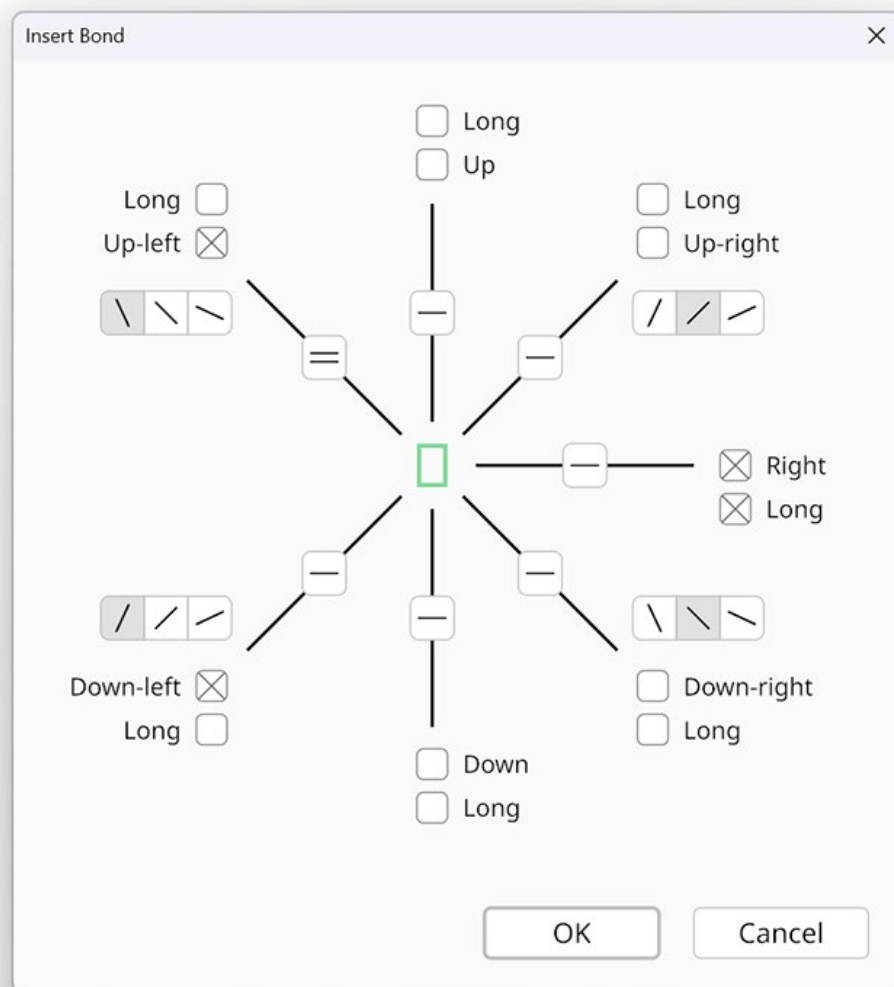
☐ Arrow 3 — — — — — — — — — — ☐ Short [≡] [≡] [≡]

☐ Lower label [≡] [≡] [≡]

OK Cancel

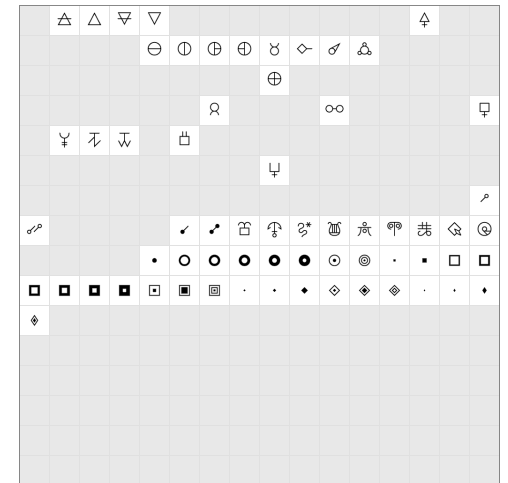
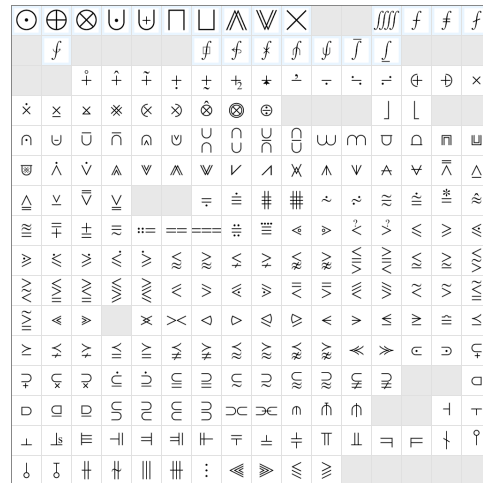
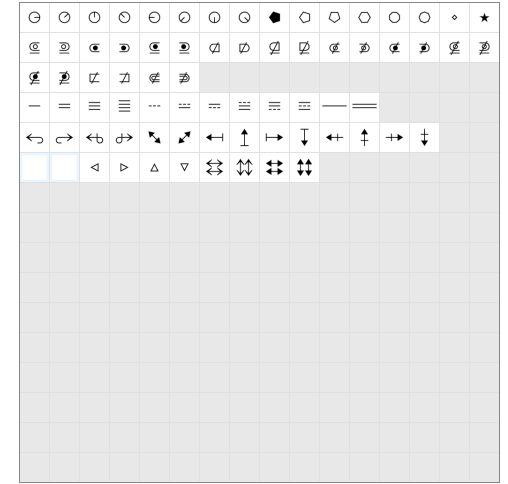
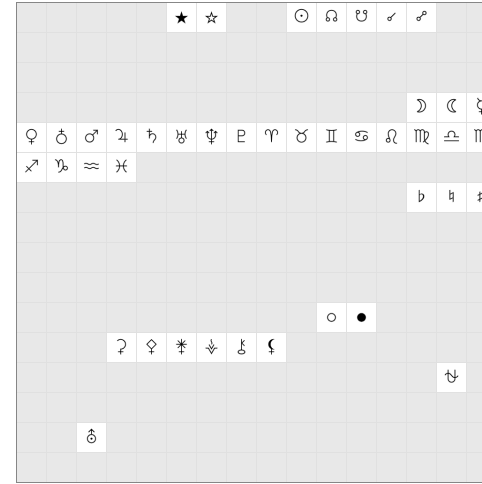
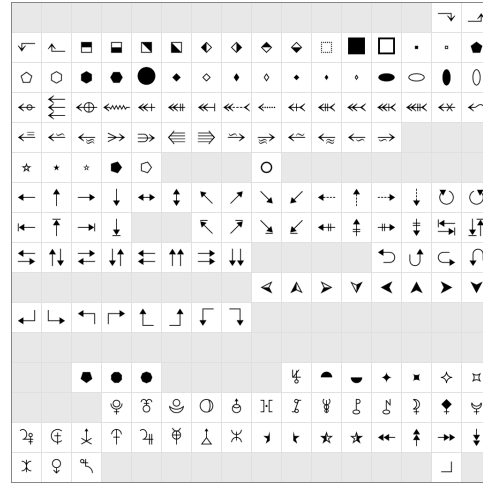
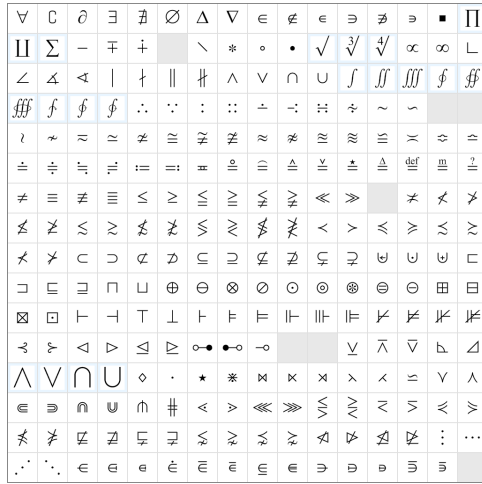
—	→	↗	↘	↙	↞	↠	↡
⊥	⊢	⊣	⌋	⌌	⌎	⌏	⌘
○	●	◻	◼	◊	◆	▷	◀
➤	➡	↪	↩	↪	⌚	⌛	
Right arrow							

Chemical Bond Builder



Single			

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:

$$\|\mathbf{Q}\|_{\circ} = \sqrt{\mathbf{Q} \mathbin{\mathbb{V}} \mathbf{\tilde{Q}}} = \mathbb{1} \sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$

- LaTeX code:

```
$$\left\|\mathbf{Q}\right\|_{\circ} = \sqrt{\mathbf{Q} \mathbin{\mathbb{V}} \mathbf{\tilde{Q}}} = \mathbb{1} \sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$
```

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

```


$$\left\| \mathbf{Q} \right\|_{\circ} = \sqrt{\mathbf{Q} \mathbin{\mathbf{\smash{\mathbf{\underset{\Large Q}}{\mathbf{\tilde{Q}}}}}} \mathbf{Q}} = \mathbb{1} \sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$


```

$$\|\mathbf{Q}\|_{\circ} = \sqrt{\mathbf{Q} \mathbin{\mathbf{\smash{\mathbf{\underset{\Large Q}}{\mathbf{\tilde{Q}}}}}} \mathbf{Q}} = \mathbb{1} \sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$

LaTeX Tediousness

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

$$\|\mathbf{Q}\|_{\circ} = \sqrt{\mathbf{Q} \cdot \mathbf{Q}} = 1 \sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$

- MathJax output for comparison:

$$\|\mathbf{Q}\|_{\circ} = \sqrt{\mathbf{Q} \cdot \mathbf{Q}} = 1 \sqrt{Q_{vx}^2 + Q_{vy}^2 + Q_{vz}^2 + Q_{vw}^2}$$

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

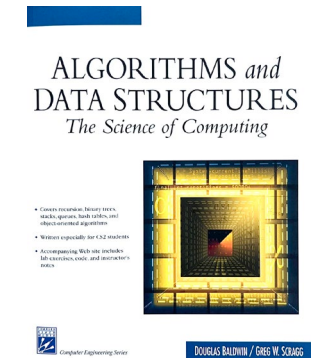
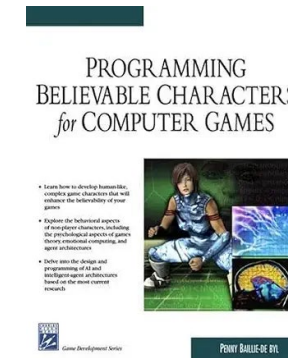
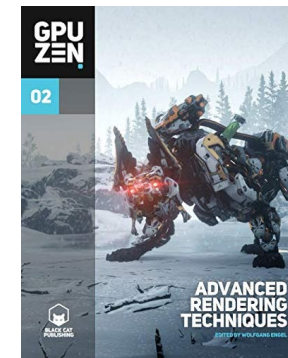
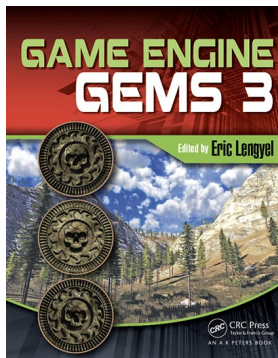
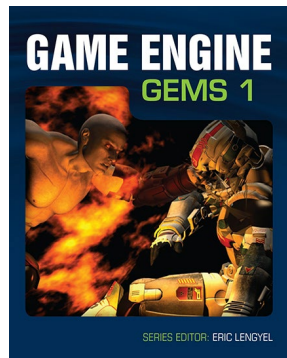
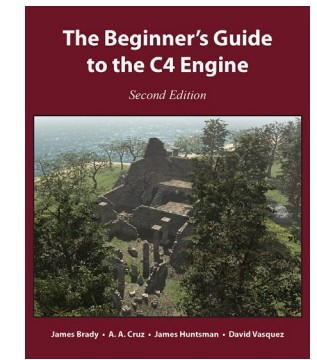
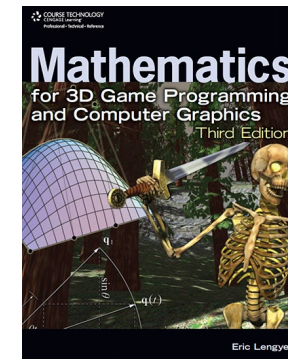
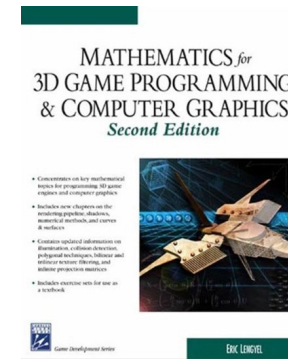
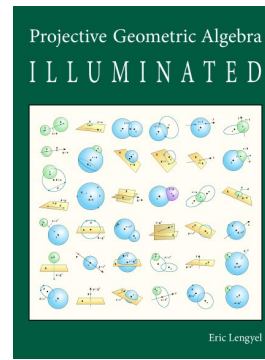
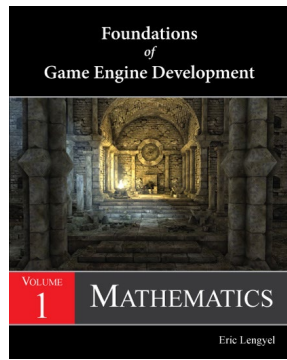
- Pro version of equation editor shipped with Word in 90s
- Comprehensive feature set
- High-quality output
- Excellent integration with Microsoft Word

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!

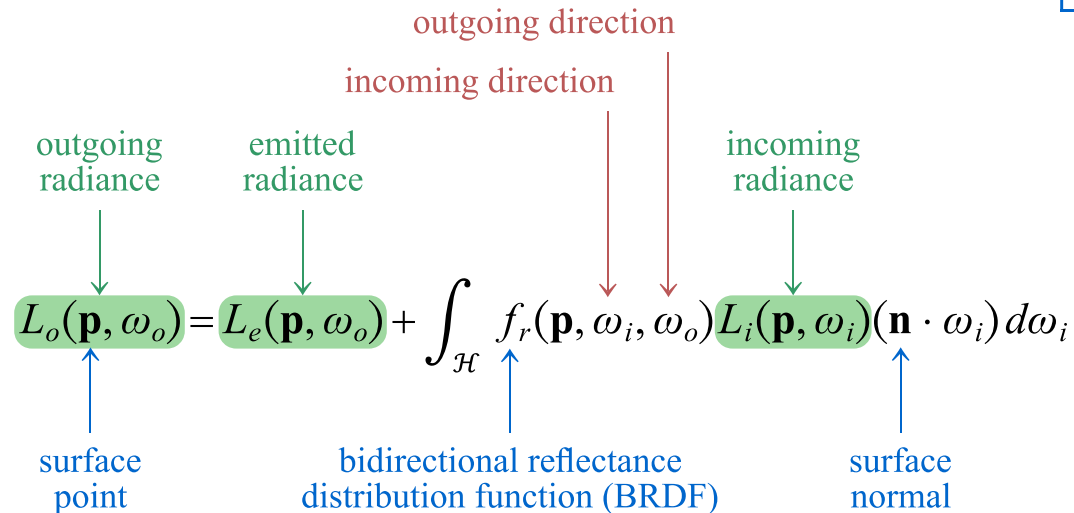
Needed Features

- 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

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

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



The diagram illustrates the rendering equation with various components labeled:

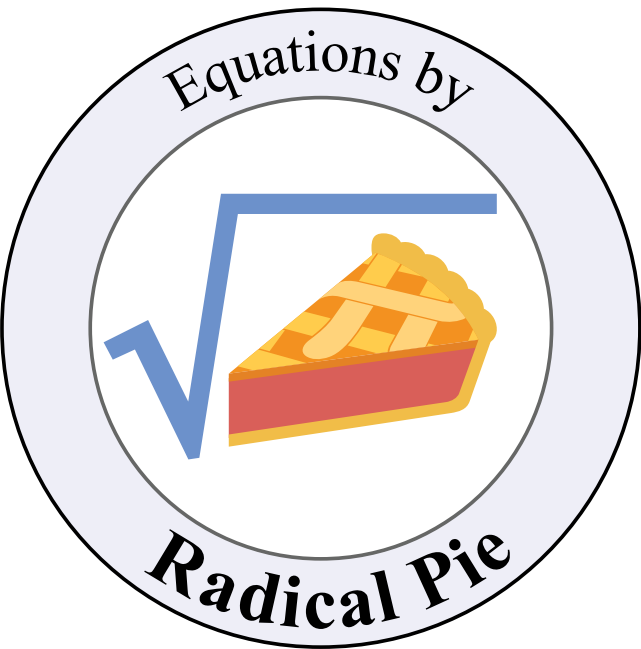
- outgoing radiance** (green arrow pointing to $L_o(\mathbf{p}, \omega_o)$)
- emitted radiance** (green arrow pointing to $L_e(\mathbf{p}, \omega_o)$)
- incoming direction** (red arrow pointing to ω_i)
- incoming radiance** (green arrow pointing to $L_i(\mathbf{p}, \omega_i)$)
- outgoing direction** (red arrow pointing to ω_o)
- surface point** (blue arrow pointing to $\mathbf{p}$)
- bidirectional reflectance distribution function (BRDF)** (blue arrow pointing to $f_r(\mathbf{p}, \omega_i, \omega_o)$)
- surface normal** (blue arrow pointing to $\mathbf{n}$)

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

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



Cocarrier Direction

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

Carrier Plane

Cocarrier Moment

Flat Line

(when $c_{gx} = c_{gy} = c_{gz} = c_{gw} = 0$)

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

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

$$\begin{aligned} M_{\odot} &= 1.989 \times 10^{30} \text{ kg} \\ R_{\odot} &= 6.957 \times 10^8 \text{ m} \end{aligned}$$

$$\begin{aligned} M_{\oplus} &= 5.972 \times 10^{24} \text{ kg} \\ R_{\oplus} &= 6.3781 \times 10^6 \text{ m} \end{aligned}$$

$$\begin{aligned} \mathbf{a} \mathbin{\mathbb{A}}_k \mathbf{b} &= \sum_{\mathbf{c} \in B_k} (\mathbf{c} \mathbin{\mathbb{V}} \mathbf{a}) \wedge (\mathbf{b} \mathbin{\mathbb{V}} \mathbf{c}^*) \\ \mathbf{a} \mathbin{\mathbb{A}} \mathbf{b} &= \sum_{k=0}^n (-1)^{k(k-1)/2} \mathbf{a} \mathbin{\mathbb{A}}_k \mathbf{b} \end{aligned}$$

Ricci tensor

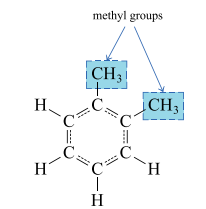
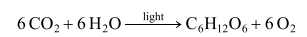
Metric tensor

Scalar curvature

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R$$

Einstein tensor

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$
$$\begin{aligned} \nabla \cdot \mathbf{E} &= \frac{\rho}{\epsilon_0} \\ \nabla \cdot \mathbf{B} &= 0 \\ \nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla \times \mathbf{B} &= \mu_0 \mathbf{J} + \frac{1}{c^2} \frac{\partial \mathbf{E}}{\partial t} \end{aligned}$$



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

outgoing direction

incoming direction

outgoing radiance

emitted radiance

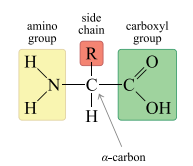
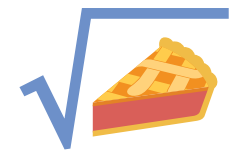
incoming radiance

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

surface point

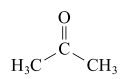
bidirectional reflectance distribution function (BRDF)

surface normal



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

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



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

1

$\mathbf{e}_1$

$\mathbf{e}_2$

$\mathbf{e}_3$

$\mathbf{e}_{23}$

$\mathbf{e}_{31}$

$\mathbf{e}_{12}$

1

$$\mathbf{M} = \begin{bmatrix} \boxed{1} & & & & & & \\ & \boxed{\mathbf{m}} & & & & & \\ & & \boxed{\mathbf{m}} & & & & \\ & & & \boxed{\mathbf{m}} & & & \\ & & & & \boxed{\mathbf{m}} & & \\ & & & & & \boxed{\mathbf{m}} & \\ & & & & & & \boxed{1} \end{bmatrix}$$

scalar

vector

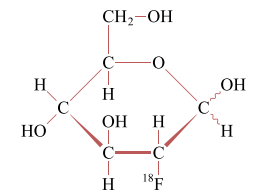
bivector

antiscalar

det $\mathbf{m}$

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

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



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

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		

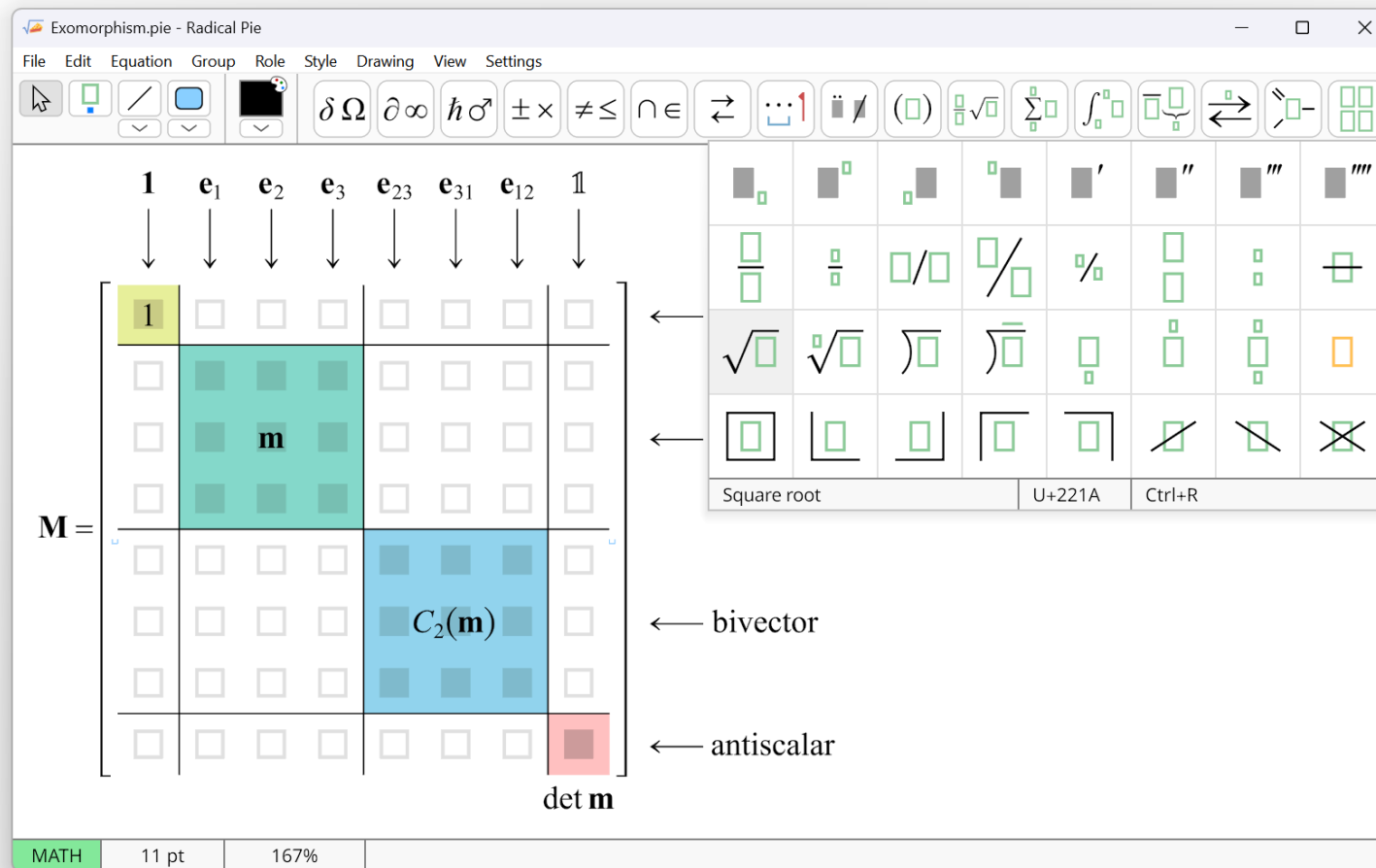
Basics

- 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

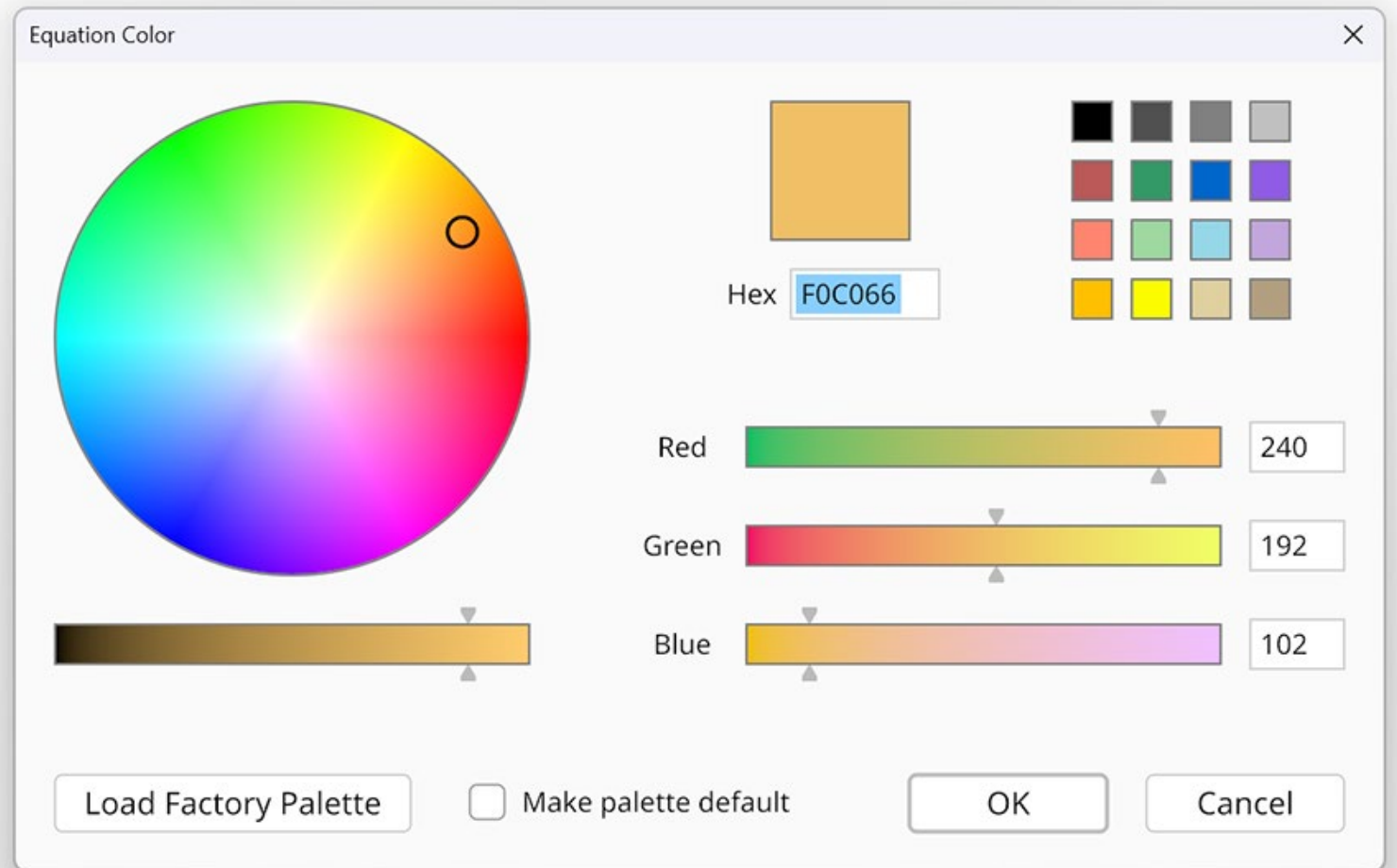


Dialog Boxes

- 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

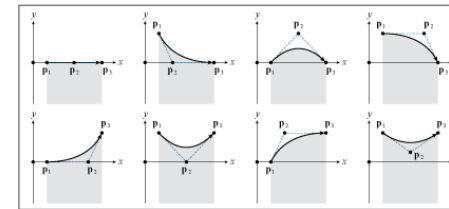


The Slug Algorithm
sluglibrary.com

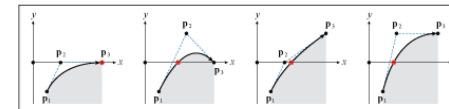
Root Eligibility

Class	$y_3 < 0$	$y_2 < 0$	$y_1 < 0$	Root 2	Root 1
A	0	0	0	0	0
B	0	0	1	1	0
C	0	1	0	1	1
D	0	1	1	1	0
E	1	0	0	0	1
F	1	0	1	1	1
G	1	1	0	0	1
H	1	1	1	0	0

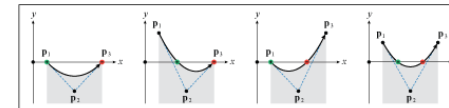
Class A



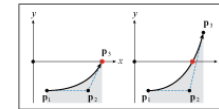
Class B



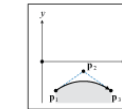
Class C



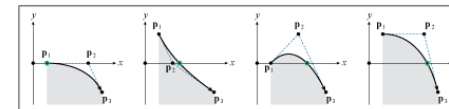
Class D



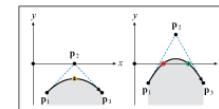
Class H



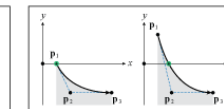
Class E



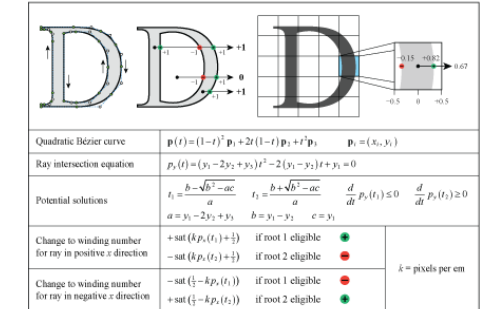
Class F



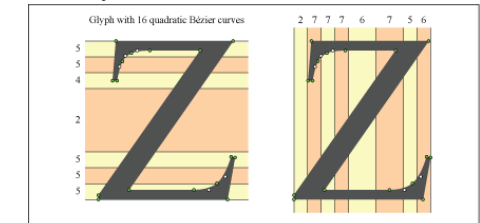
Class G



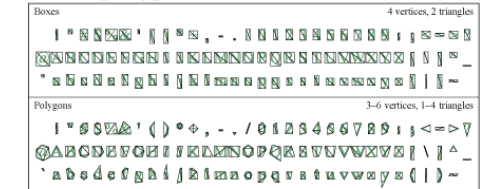
Winding Number



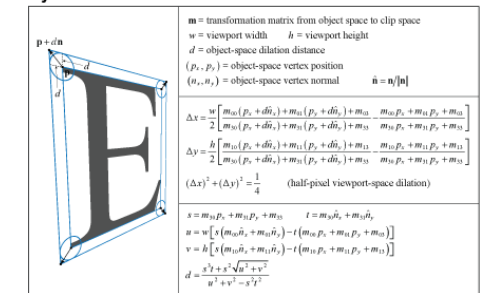
Geometry Bands



Bounding Polygons



Dynamic Dilation

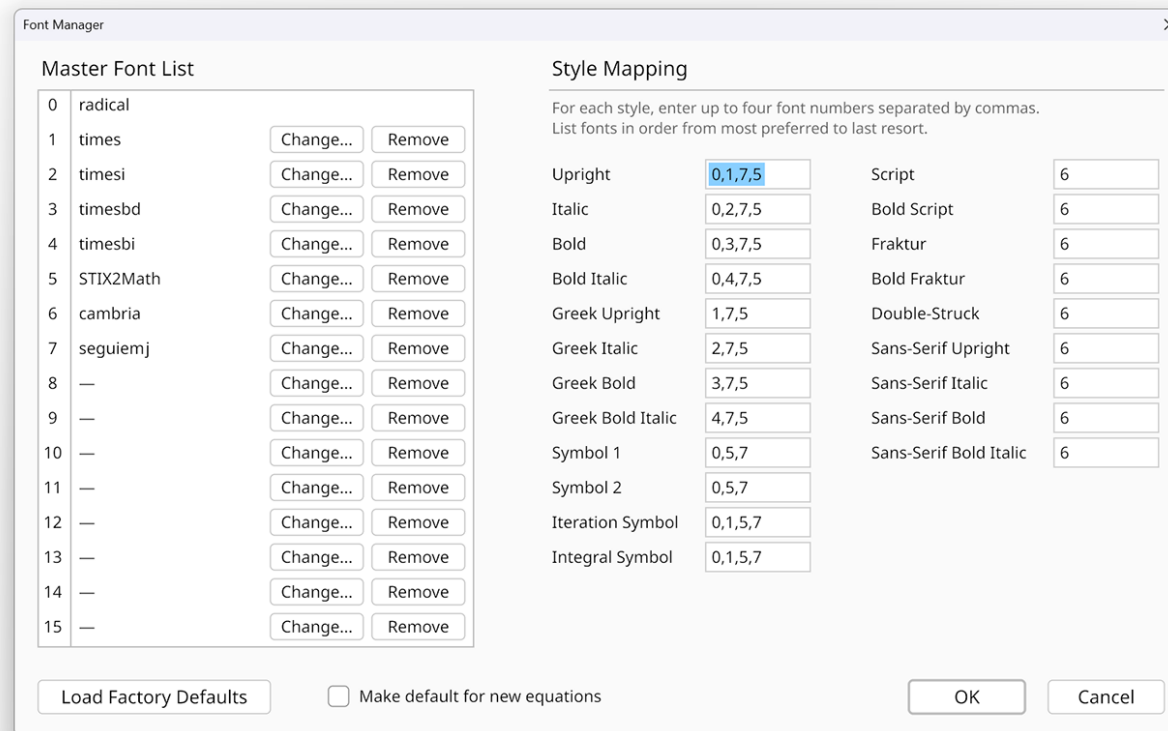


Slug Library

- 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

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad \left\{ \begin{matrix} x \\ y \\ z \end{matrix} \right\} \quad \left\langle \begin{matrix} x \\ y \\ z \end{matrix} \right\rangle \quad \left\langle\!\!\left\langle \begin{matrix} x \\ y \\ z \end{matrix} \right\rangle\!\!\right\rangle \quad \left[\!\!\left[\begin{matrix} x \\ y \\ z \end{matrix}\right]\!\!\right] \quad \left| \begin{matrix} x \\ y \\ z \end{matrix} \right| \quad \left\| \begin{matrix} x \\ y \\ z \end{matrix} \right\| \quad \sqrt{a^2 + b^2} \quad \sqrt{\frac{m_x^2 + m_y^2 + m_z^2}{v_x^2 + v_y^2 + v_z^2}}$$

$$\begin{array}{ccccccccc} \overline{abcde} & \overline{\overline{abcde}} & \widehat{abcde} & \frown abcde & \smile abcde & \widehat{abcde} & \widetilde{abcde} & \overline{abcde} & \overbrace{abcde} \\ \underline{abcde} & \underline{\underline{abcde}} & \underbrace{abcde} & \underbrace{abcde} & \underbrace{abcde} & \underbrace{abcde} & \underbrace{abcde} & \boxed{abcde} & \underbrace{abcde} \\ \overleftarrow{abcde} & \overrightarrow{abcde} & \longleftrightarrow abcde & \overleftarrow{abcde} & \overrightarrow{abcde} & \overleftarrow{abcde} & \overrightarrow{abcde} & \overrightarrow{abcde} & \overrightarrow{abcde} \\ \overleftarrow{\underline{abcde}} & \underline{\overrightarrow{abcde}} & \overleftrightarrow{\underline{abcde}} & \underline{\overleftarrow{abcde}} & \underline{\overrightarrow{abcde}} & \underline{\overleftarrow{abcde}} & \underline{\overrightarrow{abcde}} & \underline{\overrightarrow{abcde}} & \underline{\overrightarrow{abcde}} \end{array}$$

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

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

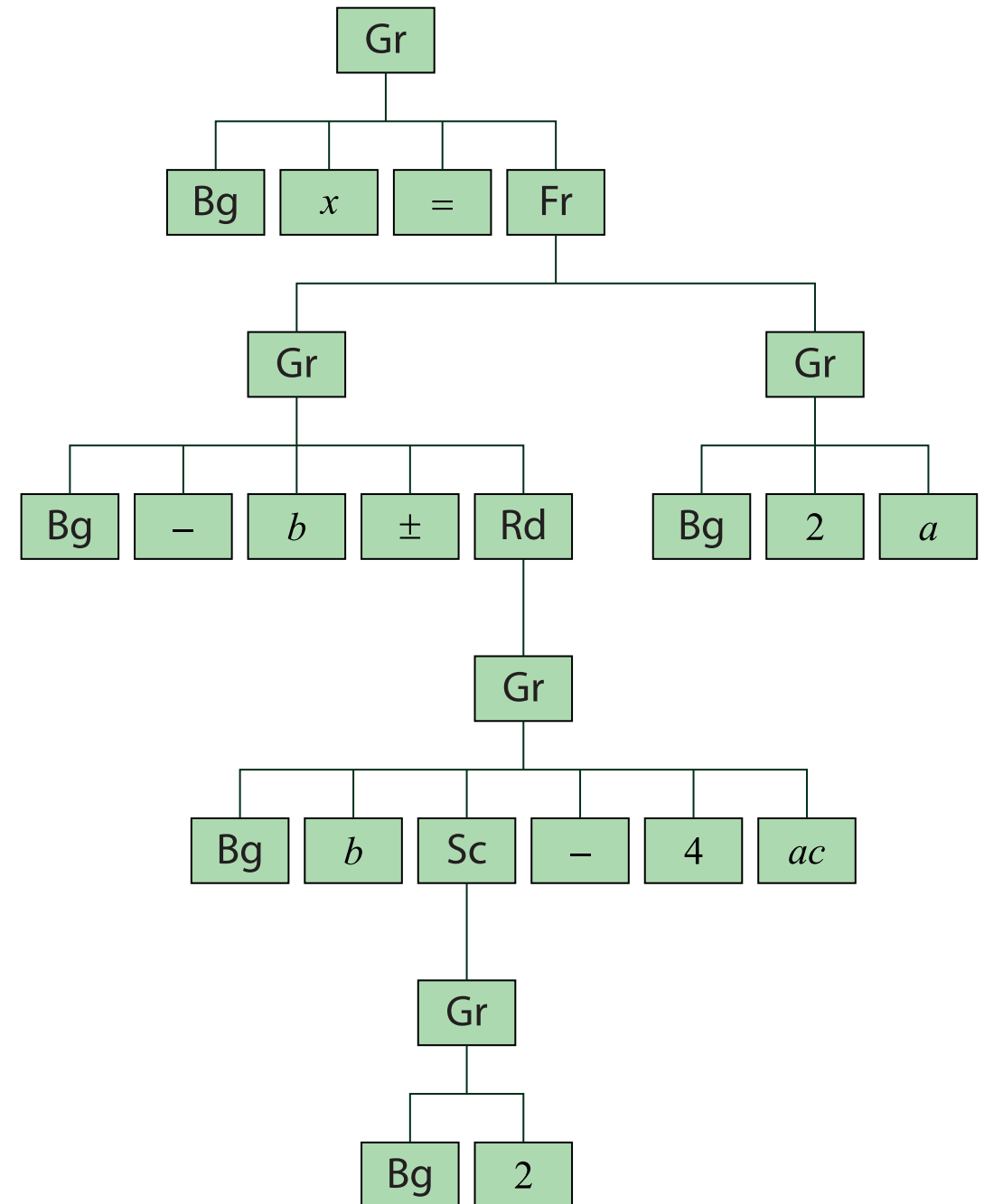
	Radical Pie	MathType	LaTeX (MathJax)	Office
Original	$\overline{abcde}$	$\overline{abcde}$	$\overline{abcde}$	$\overline{abcde}$
	$\underline{abcde}$	not available	not available	not available
Copy/paste into Illustrator	$\overline{abcde}$	 $\overline{abcde}$	$abcde\tilde{}$	$a\,b\,c\,a\,e$

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

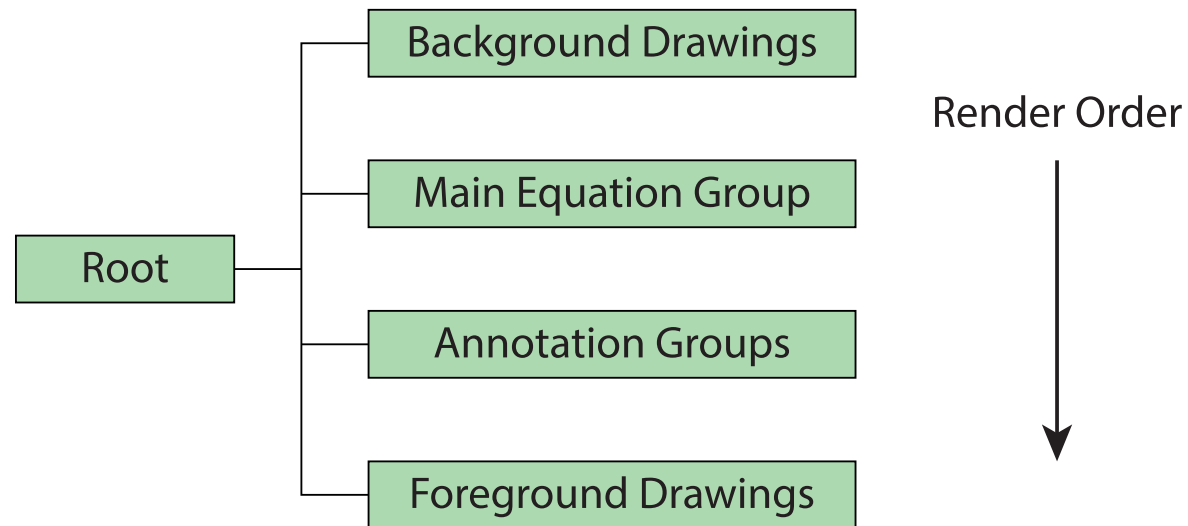
- A “symbol” is the smallest piece of an equation
 - A variable or function
 - An operator or relation
 - A literal number
 - A text label
- Every symbol has a *role* and a *style*
- One symbol can consist of several adjacent characters having the same role and style

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

The screenshot shows the Radical Pie software interface with the equation $L_o(\mathbf{p}, \omega_o) = L_e(\mathbf{p}, \omega_o) + \int_{\mathcal{H}} f_r(\mathbf{p}, \omega_i, \omega_o) L_i(\mathbf{p}, \omega_i) (\mathbf{n} \cdot \omega_i) d\omega_i$. The caret is positioned at the end of the equation, and the displayed anchors are blue dots forming a rectangular box around the entire equation.

Rendering.pie - Radical Pie

File Edit Equation Group Role Style Drawing View Settings

MATH 11 pt 236%

The screenshot shows the same Radical Pie software interface with the same equation. The caret is now positioned at the end of the integral term, and the displayed anchors are blue dots forming a rectangular box around only that specific term.

Rendering.pie - Radical Pie

File Edit Equation Group Role Style Drawing View Settings

MATH 11 pt 236%

Anchors

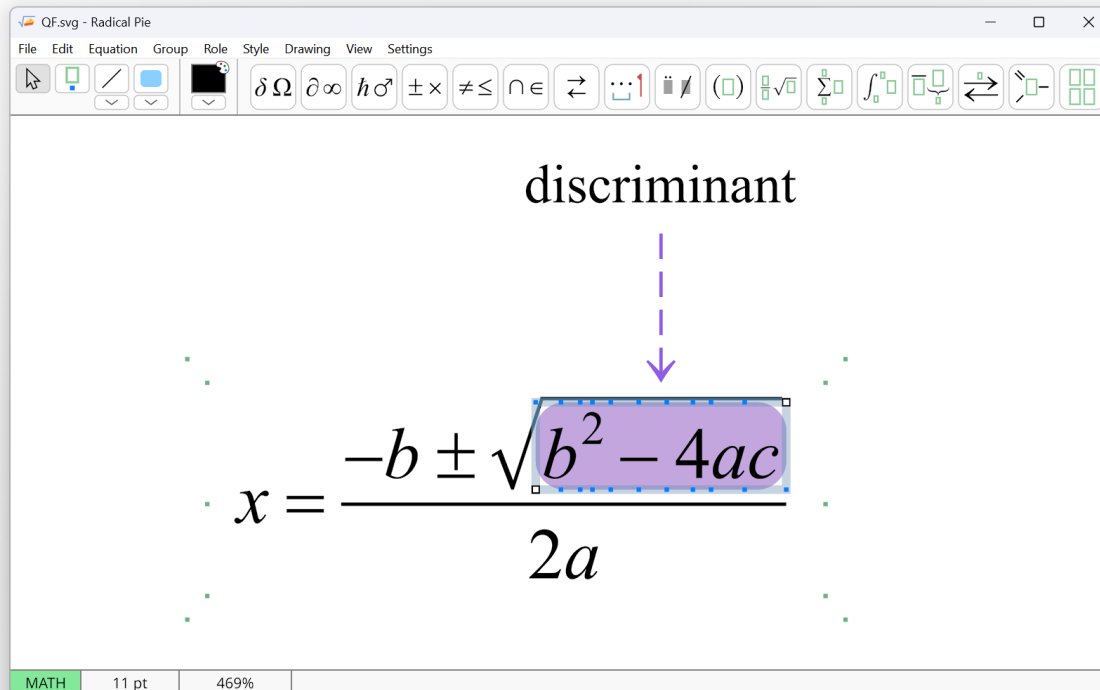
- Matrices advertise many more anchors

The screenshot shows the Radical Pie software interface with a 3x3 matrix displayed on a grid. The matrix is defined by the equation $\mathbf{m} = \begin{bmatrix} m_{00} & m_{01} & m_{02} \\ m_{10} & m_{11} & m_{12} \\ m_{20} & m_{21} & m_{22} \end{bmatrix}$. The matrix elements are surrounded by numerous small purple dots, which represent anchors. The software interface includes a menu bar (File, Edit, Equation, Group, Role, Style, Drawing, View, Settings) and a toolbar with various icons. The status bar at the bottom indicates "MATH", "11 pt", and "400%".

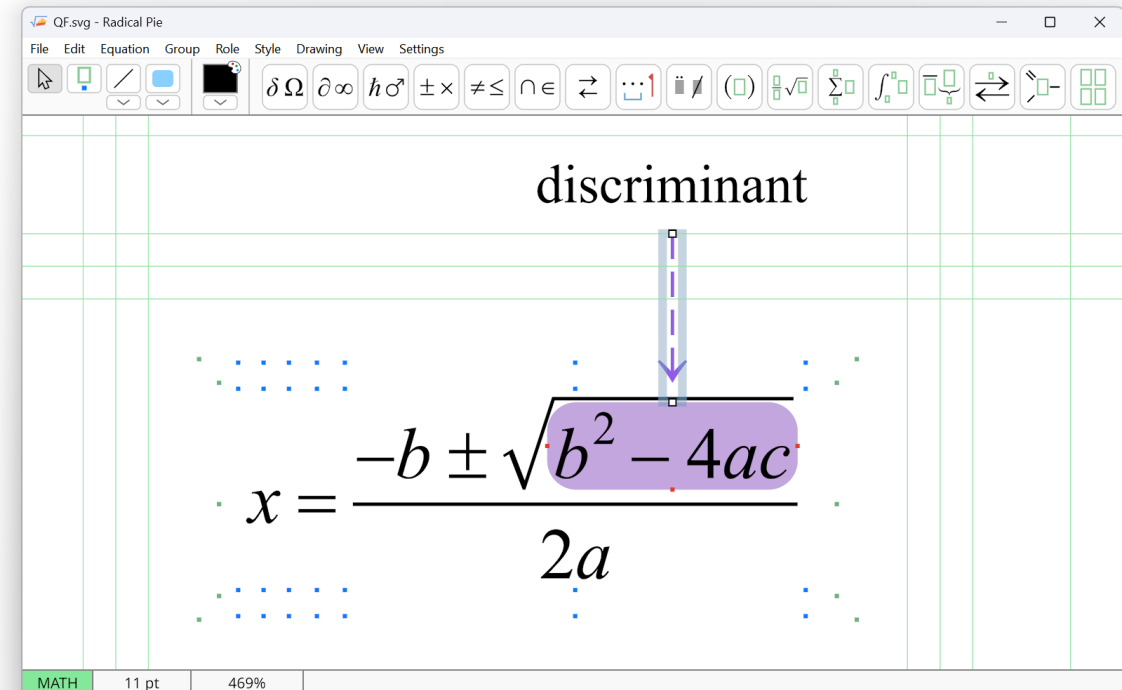
The screenshot shows the same Radical Pie software interface with the same 3x3 matrix. However, in this version, the matrix elements are surrounded by numerous small blue dots, representing a different set of anchors. The software interface and status bar are identical to the previous screenshot.

Node Graph

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



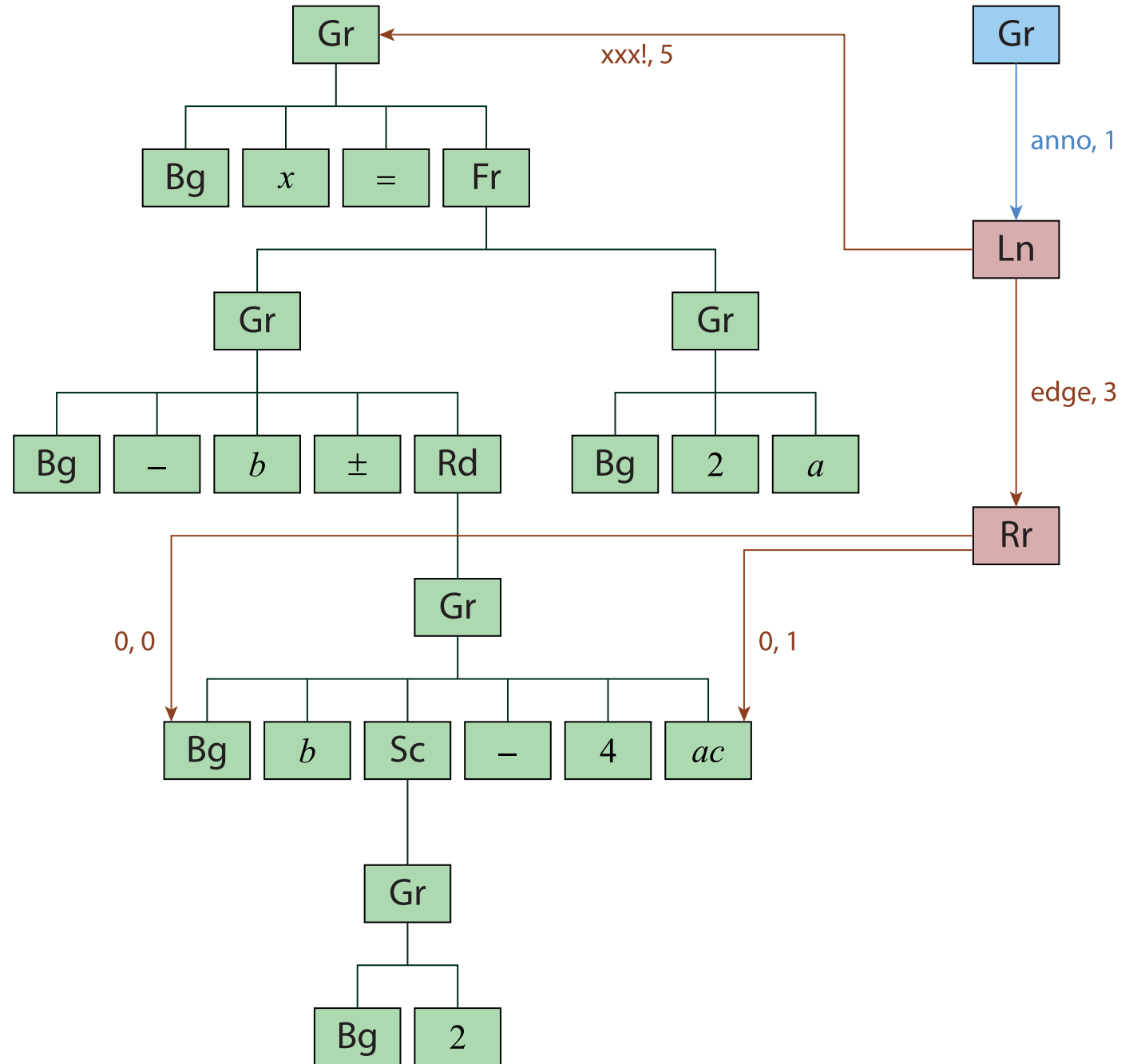
The screenshot shows the Radical Pie software interface. The title bar reads "QF.svg - Radical Pie". The menu bar includes "File", "Edit", "Equation", "Group", "Role", "Style", "Drawing", "View", and "Settings". The toolbar contains various mathematical symbols and drawing tools. The main workspace displays the quadratic formula $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$. The expression $b^2 - 4ac$ under the square root is highlighted with a purple rounded rectangle. A dashed purple arrow points from the word "discriminant" above to this highlighted expression. The status bar at the bottom shows "MATH", "11 pt", and "469%".



This screenshot is similar to the previous one, showing the same quadratic formula and highlighted discriminant. However, a light blue selection box is now visible around the word "discriminant". Additionally, a dashed purple arrow points from the selection box down to the highlighted expression $b^2 - 4ac$. The status bar at the bottom remains the same, showing "MATH", "11 pt", and "469%".

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

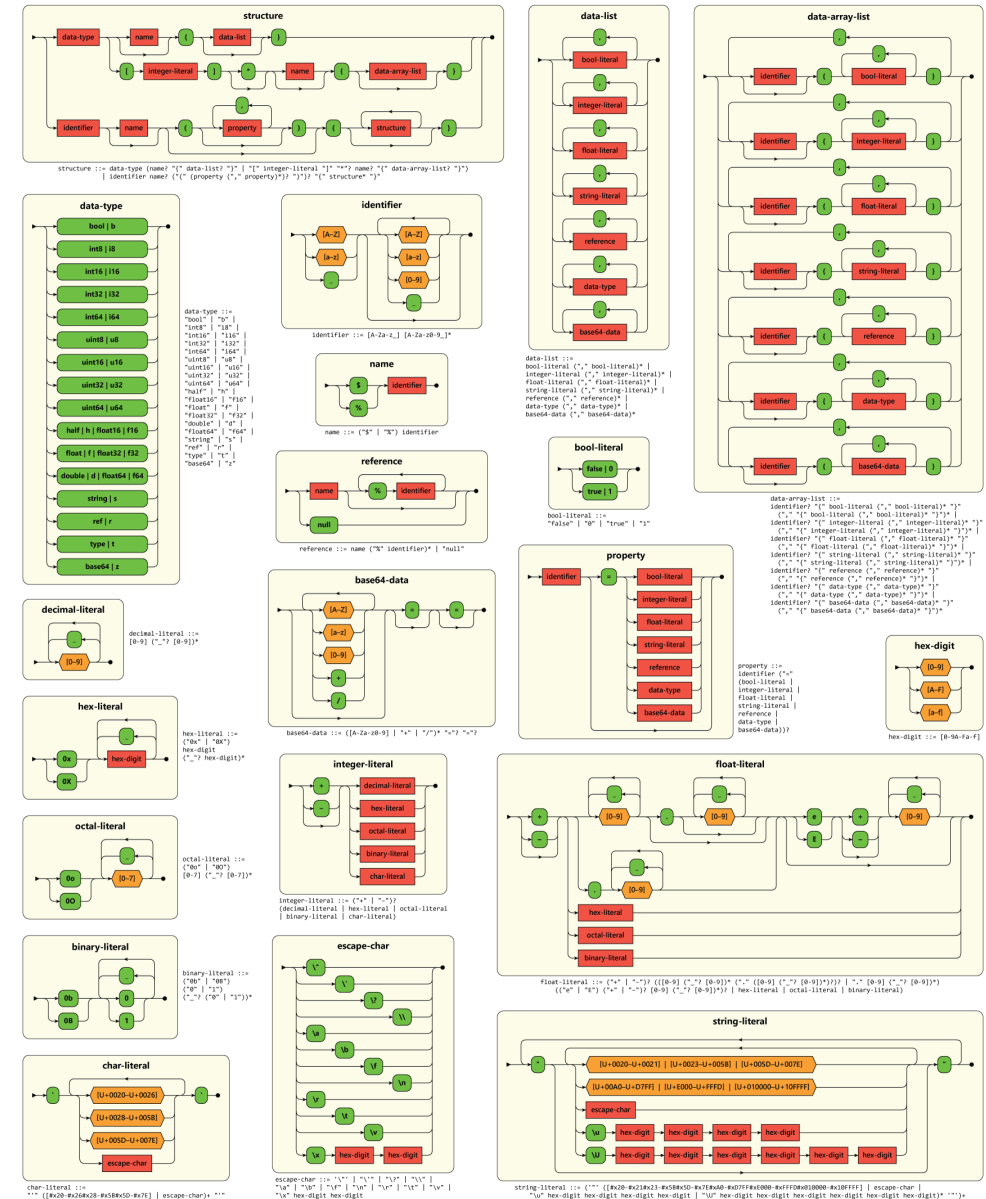
- Obviously, we need a way to save and reload equations
- Not only for saving files, but for storing undo / redo snapshots
- Format needs to capture tree and graph structures
- Preferably text-based to make embedding easy in other formats like SVG

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

Open Data Description Language

openddl.org

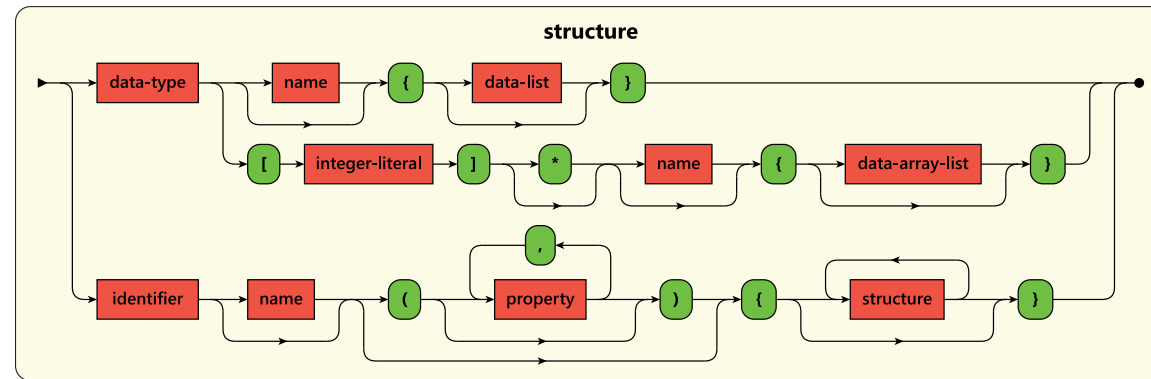


OpenDDL

- 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='supr')
            {
              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='supr')
  {
    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}
  }
}
```

discriminant

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

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

OpenDDL comment

List of filled paths

[illegible]

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

Equation Design

$\delta \Omega$

Common

$\pm \times$

Symbols

$\hat{\cdot}$

Marks

$(\square)$

Brackets

$\square$

Scripts

$\frac{\square}{\square}$

Fractions

$\sqrt{\square}$

Radicals

$\int \square$

Quotients

$\square$

Stacks

$\square$

Boxes

$\square$

Strikes

$\sum \square$

Iterations

$\int \square$

Integrals

$\square$

Widemarks

$\rightleftarrows$

Arrows

$\curvearrowright$

Charms

$\square$

Bonds

$\square$

Matrices

$(qE + mg)$

Points (pt) = font size × ems
1 em = 18 math units (mu)

Exterior spacing	2.0	mu
Interior spacing	1.0	mu
Upper vertical extent	1.0	mu
Lower vertical extent	3.0	mu
Min vertical gap	0.5	mu
Paranthesis max glyph scale	0.0	%
Paranthesis hook width	0.375	em
Paranthesis hook height	1.0	em
Paranthesis control position	62.5	%
Paranthesis main thickness	1.5	mu
Paranthesis end thickness	0.5	mu
Bracket max glyph scale	0.0	%
Bracket width	0.28	em
Bracket main thickness	1.25	mu
Bracket end thickness	0.8525	mu
Double bracket spacing	1.5	mu
Angle bracket width	0.25	em
Angle bracket thickness	0.8525	mu
Double angle bracket spacing	1.5	mu
Brace max glyph scale	150.0	%
Brace hook width	0.25	em
Brace hook height	0.5	em
Brace control position	90.0	%
Brace main thickness	1.5	mu
Brace end thickness	0.5	mu
Brace apex thickness	0.75	mu
Tortoise shell max glyph scale	0.0	%
Tortoise shell hook width	0.25	em
Tortoise shell hook height	0.15	em
Tortoise shell main thickness	1.25	mu
Tortoise shell end thickness	0.8525	mu
Vertical bar thickness	0.8525	mu
Double vertical bar spacing	1.705	mu
Floor / ceiling width	0.25	em
Floor / ceiling main thickness	0.8525	mu
Floor / ceiling end thickness	0.8525	mu

Load Factory Defaults

☐ Make default for new equations

OK

Cancel

Drawing Design

Anchors

Rails

Lines

Joists

Shapes

Annotations

Stroke width 1

0.045

em

Stroke width 2

0.0675

em

Stroke width 3

0.09

em

Stroke width 4

0.135

em

Stroke width 5

0.18

em

Dash length 1

0.09

em

Gap length 1

0.135

em

Dash length 2

0.36

em

Gap length 2

0.18

em

Dash length 3

0.54

em

Gap length 3

0.36

em

Overshoot anchor offset

0.27

em

Undershoot anchor offset

0.27

em

Circle scale

600.0

%

Square scale

600.0

%

Wedge length scale

800.0

%

Wedge width scale

423.0

%

Arrow 1 length scale

507.000

%

Arrow 1 width scale

423.0

%

Arrow 1 inner thickness scale

300.0

%

Arrow 1 outer thickness scale

25.0

%

Arrow 1 curvature

0.0

%

Arrow 2 length scale

507.000

%

Arrow 2 width scale

423.0

%

Arrow 2 inner thickness scale

188.0

%

Arrow 2 outer thickness scale

70.0

%

Arrow 2 curvature

15.0

%

Points (pt) = font size × ems
1 em = 18 math units (mu)

Load Factory Defaults

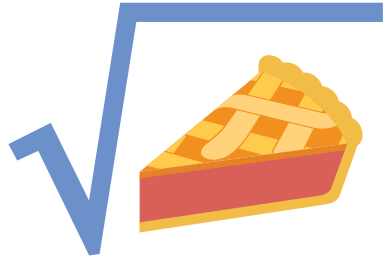
☐ Make default for new equations

OK

Cancel

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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