

10 years of OpenType math font development

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Overview

- 25 years of BachoT_EX conferences
- 25+ years of font development at BachoT_EX
 - Polish fonts in MF, PS (1990s)
 - Latin Modern fonts (2002-07)
 - T_EX Gyre fonts (2007-09)
 - LM and TG in OpenType (2007-09)
 - LM and TG math fonts (2011-15)

Overview

- 25+ years of math font activities
 - working group on 8-bit math font encodings (1992–93)
 - prototype implementation of 8-bit math fonts (1997–98)
 - Unicode standardization of math symbols (1998–2000)
 - waiting for the STIX fonts (2000–2010)
 - finally, MS arrived with OpenType math fonts (2007)

Overview

- 10 years of OpenType math fonts
 - 2007: engine support in MS Office; Cambria Math
 - 2008: engine support in Xe \TeX , XeLa \TeX ; Asana Math
 - 2009: engine support in Lua \TeX , LuaLa \TeX , Con \TeX t
 - 2010: engine + macros + fonts in \TeX Live; XITS Math
 - 2011: Latin Modern Math (GUST team)
 - 2011-12: Lucida Math (TUG, Bigelow & Holmes)
 - 2012-15: \TeX Gyre Math + DejaVu (GUST team)

What has been achieved in nearly 10 years?

- OpenType math engine support: mostly stable
 - \TeX engines: Lua \TeX 1.0x, Xe \TeX 0.9999x
 - MS engines: Office 2007, 2010, etc
 - Browser support: Mozilla Firefox + PlugIns
 - no other engines: ???
- macro package support: mostly stable
 - LuaLa \TeX and XeLa \TeX (via unicode-math)
 - Con \TeX t Mk IV
 - Plain Lua \TeX (via luatex-plain)
- OpenType math font development: ongoing
 - some 12-15 fonts available
 - some still under development

Choices for OpenType math fonts

- Choices of math fonts by origin
 - traditional \TeX fonts: Latin Modern (+ Euler)
 - traditional PS fonts: \TeX Gyre, STIX/XITS
 - other designs: Cambria, Lucida, Minion, Libertinus, DejaVu
- Choices of math fonts by developer
 - GUST team: Latin Modern, \TeX Gyre, DejaVu
 - Khaled Hosny: XITS, Lucida, Libertinus
 - other developers: STIX, Cambria, Asana, Minion
- Choices of math fonts by availability
 - from CTAN: Latin Modern, \TeX Gyre, XITS, Asana, Libertinus
 - sold commercially: Lucida (via TUG), Minion
 - as system fonts: Cambria (on Windows 7 or 10)

Choices of OpenType math fonts

- Choices of math fonts by release date
 - Cambria Math, since 2007
 - Asana Math, since 2008
 - Neo Euler, since 2009 (abandoned)
 - XITS Math, since 2010 (from STIX 1.0)
 - STIX Math, June 2013 (from STIX 1.1)
 - Latin Modern Math, May 2011
 - Minion Math, October 2011
 - Lucida Math, March 2012
 - T_EX Gyre Pagella Math, May 2012
 - T_EX Gyre Termes Math, Sept 2012
 - T_EX Gyre Bonum Math, May 2013
 - T_EX Gyre Schola Math, May 2014
 - (T_EX Gyre) DejaVu Math, May 2015/16
 - Libertinus Math, since 2016
 - STIX Two Math, Dec 2016

Choices of OpenType math fonts

- Choices of math fonts by completeness

XITS Math	1305 symbols + 1167 alphabetic
STIX Two	1305 symbols + 1167 alphabetic
Minion	1235 symbols + 277 alphabetic
Asana	1153 symbols + 1165 alphabetic
Cambria	1085 symbols + 1164 alphabetic
Lucida	980 symbols + 1036 alphabetic
TeX Gyre	549 symbols + 1164 alphabetic
LM Math	548 symbols + 1108 alphabetic
Libertinus	463 symbols + 761 alphabetic
Neo Euler	250 symbols + 395 alphabetic

- Choices of bold math fonts

XITS Bold	500 symbols + 1090 alphabetic
Lucida Demi	473 symbols + 958 alphabetic

Comparison of OpenType math fonts

- Completeness
 - Completeness of math symbols
 - Completeness of math alphabets
- Design Issues
 - Choices of Scripts, Fraktur, BBold
 - Choices of matching serif vs. sans-serif?
- Quality Issues
 - Spacing and accent placement
 - Superscript/Subscript placement

Completeness of math symbols

- Unicode math defines thousands of math symbols
 - scope of math vs. non-math symbols isn't very clear
 - math and non-math (technical, dingbats) are intermixed
 - Unicode is a moving target (Unicode 10.0 approaching)
 - some Unicode versions added just a few symbols
 - some Unicode versions added lots of new symbols (100+ new arrows in Unicode 7.0)
- OpenType math fonts can choose what to implement
 - most fonts do not provide all math symbols
 - many fonts have at least some missing math symbols
 - support for wide over/under accents varies a lot

Completeness of math symbols

- How complete are various fonts?
 - almost fully complete: XITS/STIX
 - mostly complete: Minion, Asana
 - in between: Cambria (updated), Lucida
 - middle ground: Latin Modern, T_EX Gyre
 - least complete: Libertinus, Neo Euler
- How much is good enough?
 - it is perfectly OK to limit the scope of symbols
 - all LM/TG fonts provide the same common subset
 - Cambria, Lucida have some gaps in the LM/TG subset

Completeness of math alphabets

- Unicode math defines dozens of math alphabets
 - 4x serif (regular, italic, bold, bold italic / Latin + Greek)
 - 4x sans (regular, italic, bold, bold italic / Latin + Greek)
 - 2x Script (regular, bold / upper, lower)
 - 2x Fraktur (regular, bold / upper, lower)
 - 1x BBold (regular / upper, lower, numerals)
- some math alphabets have clear function
 - 4x serif (regular, italic, bold, bold italic / Latin + Greek)
 - 2x bold sans (bold, bold italic / Latin + Greek)
 - 2x Script, 2x Fraktur, 1x BBold
- some math alphabets are dubious
 - 2x light sans (regular, italic / Latin only)
 - 1x typewriter

Completeness of math alphabets

- OpenType fonts can choose what to implement
- some fonts have some missing math alphabets
 - (bold sans Greek, bold sans italic Greek)
 - lowercase Script, bold Script, bold Fraktur
 - lowercase BBold, numerals BBold
- some fonts may provide additional alphabets
 - alternate Script / Calligraphic
 - additional variants (BBold italic)
 - additional bold math fonts

Completeness of math alphabets

- How complete are various fonts?
 - mostly complete: XITS/STIX, T_EX Gyre, Asana, Cambria
 - slightly less complete: Latin Modern, Lucida
 - least complete: Minion, Libertinus, Neo Euler
- How much is good enough?
 - all T_EX Gyre fonts provide nearly the full scope
 - Latin Modern, Lucida only slightly behind
 - most gaps depend on availability of glyph designs

Mixing and matching fonts: Script, Fraktur, BBold

- Unicode math combines several math alphabets
- OpenType math fonts need to choose matching fonts
 - no problem for comprehensive families (LM, Lucida)
 - non-trivial design issue for most other font families
- Choosing a matching Script or Fraktur font:
 - Which fonts are available for inclusion or reuse?
 - Script or Fraktur are very different by design
 - Script or Fraktur can be combined with many fonts
- Choosing a matching BBold (openface) font:
 - sans-serif BBold fonts are very different by design
 - serif BBold fonts constructed/derived from base font
 - serif BBold fonts need to be adjusted for each font

Mixing and matching fonts: Script, Fraktur, B-Bold

- How does Script/Calligraphic look like?

Lucida	<i>ABCXYZ abcxyz</i>	
XITS Math	<i>ABCXYZ abcxyz</i>	
TG Termes	<i>ABCXYZ abcxyz</i>	(same)
TG Bonum	<i>ABCXYZ abcxyz</i>	(same)
TG Schola	<i>ABCXYZ abcxyz</i>	(same)
TG Pagella	<i>ABCXYZ abcxyz</i>	(Odstemplik)
TG DejaVu	<i>ABCXYZ abcxyz</i>	
Cambria	<i>ABCXYZ abcxyz</i>	
LM Math	<i>ABCXYZ</i>	(Euler Script)
XITS Math	<i>ABCXYZ</i>	(StylisticSet=1)
Lucida	<i>ABCXYZ</i>	(StylisticSet=4)

Mixing and matching fonts:, Script, Fraktur, BBold

- How does Fraktur look like?

Cambria	ABCXŶZ abcæηz	
XITS Math	ABCXŶZ abcæηz	
TG Termes	ABCXŶZ abcæηz	(Leipziger Fraktur)
TG Bonum	ABCXŶZ abcæηz	(Leipziger Fraktur)
TG Pagella	ABCXŶZ abcæηz	(Euler Fraktur)
TG Schola	ABCXŶZ abcæηz	(Euler Fraktur)
TG DejaVu	ABCXŶZ abcæηz	(Euler Fraktur)
LM Math	ABCXŶZ abcæηz	(Euler Fraktur)
Lucida	ABCXŶZ abcæηz	

Mixing and matching fonts: Script, Fraktur, BBold

- How does Blackboard Bold look like?

TG Termes ABCNOPQRXYZ abc 012 (constructed)

TG Bonum ABCNOPQRXYZ abc 012 (same ???)

TG Pagella ABCNOPQRXYZ abc 012 (constructed)

TG Schola ABCNOPQRXYZ abc 012 (constructed)

TG DejaVu ABCNOPQRXYZ abc 012 (constructed)

Cambria ABCNOPQRXYZ abc 012

Minion ABCNOPQRXYZ 012

Libertinus ABCNOPQRXYZ

XITS Math ABCNOPQRXYZ abc 012

Lucida ABCNOPQRXYZ

LM Math ABCNOPQRXYZ abc 012

Mixing and matching fonts: Scripts, Fraktur, BBold

- How good are existing fonts? (Latin Modern)
 - LM mostly inherits traditional shapes from CM
 - CM Calligraphic replaced by Euler Script
 - AMS BBold replaced by Alan Jeffrey BBold => not sure
- How good are existing fonts? (T_EX Gyre)
 - TG reuses the same sets of Fraktur several times
 - TG Termes, Bonum, Scola reuse the same sets of Script
 - TG Pagella, DevaVu have very different styles of Script
 - TG derives BBold from base font in most cases
 - TG Bonum reuses BBold from TG Termes => unfinished?

Mixing and matching fonts: sans-serif vs. serif

- Choosing a matching sans-serif font:
 - Which fonts are available for inclusion or reuse?
 - Which fonts provide a bold sans Greek alphabet?
 - Is bold sans Greek distinguishable from bold serif?
 - How compatible are shapes, weight, width, italic angle?
 - sans-serif needs to be distinguishable from serif
 - sans-serif should not be too incompatible to serif
 - weight, width and italic angle may need to be adjusted
 - glyph shapes should not be too incompatible (e.g. ‘*a*’, ‘*g*’)
 - Reusing the same sans-serif may not work well

Mixing and matching fonts: sans-serif vs. serif

- How does bold sans-serif math look like?

Cambria	<i>Hambur gefons</i>	
Lucida	<i>Hambur gefons</i>	
XITS Math	<i>Hambur gefons</i>	
STIX Two	<i>Hambur gefons</i>	
LM Math	<i>Hambur gefons</i>	
TG Termes	<i>Hambur gefons</i>	(TG Heros)
TG Bonum	<i>Hambur gefons</i>	(TG Heros)
TG Schola	<i>Hambur gefons</i>	(Lato, spaced)
TG Pagella	<i>Hambur gefons</i>	(DejaVu Sans)
TG DejaVu	<i>Hambur gefons</i>	(DejaVu Sans, spaced)

Mixing and matching fonts: sans-serif vs. serif

- How does bold sans-serif compare to serif?

Cambria	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
	<i>Hamburgefons</i>	<i>ΑΒΓΧΨΩ αβγχψω</i>
	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
Lucida	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
	<i>Hamburgefons</i>	<i>ΑΒΓΧΨΩ αβγχψω</i>
	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
TG DejaVu	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
	<i>Hamburgefons</i>	<i>ΑΒΓΧΨΩ αβγχψω</i>
	Hamburgefons	ΑΒΓΧΨΩ αβγχψω

Mixing and matching fonts: sans-serif vs. serif

- How does bold sans-serif compare to serif?

XITS Math	Hamburgefons <i>Hamburgefons</i> <i>Hamburgefons</i>	ΑΒΓΧΨΩ αβγχψω <i>ΑΒΓΧΨΩ αβγχψω</i> <i>ΑΒΓΧΨΩ αβγχψω</i>
STIX Two	Hamburgefons <i>Hamburgefons</i> <i>Hamburgefons</i>	ΑΒΓΧΨΩ αβγχψω <i>ΑΒΓΧΨΩ αβγχψω</i> <i>ΑΒΓΧΨΩ αβγχψω</i>
LM Math	Hamburgefons <i>Hamburgefons</i> <i>Hamburgefons</i>	ΑΒΓΧΨΩ αβγχψω <i>ΑΒΓΧΨΩ αβγχψω</i> <i>ΑΒΓΧΨΩ αβγχψω</i>

Mixing and matching fonts: sans-serif vs. serif

- How does bold sans-serif compare to serif?

TG Pagella	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
	<i>Hamburgefons</i>	<i>ΑΒΓΧΨΩ αβγχψω</i>
(DejaVu)	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
TG Termes	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
	<i>Hamburgefons</i>	<i>ΑΒΓΧΨΩ αβγχψω</i>
(TG Heros)	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
TG Bonum	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
	<i>Hamburgefons</i>	<i>ΑΒΓΧΨΩ αβγχψω</i>
(TG Heros)	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
TG Schola	Hamburgefons	ΑΒΓΧΨΩ αβγχψω
	<i>Hamburgefons</i>	<i>ΑΒΓΧΨΩ αβγχψω</i>
(Lato)	Hamburgefons	ΑΒΓΧΨΩ αβγχψω

Mixing and matching fonts: sans-serif vs. serif

- How good are existing fonts? (T_EX Gyre)
 - TG integrates different sets of sans-serif into serif fonts
 - some combinations work well, some not so well
 - width and weight also need to match besides size
 - matching shapes (e.g. ‘*a*’, ‘*g*’) would also be nice
- Some observations / Suggestions
 - Termes, Pagella could use a lighter sans-serif
 - Bonum clearly needs a heavier sans-serif, e.g. DejaVu
 - shapes of Lato might be more compatible with Pagella
 - shapes of Heros might be more compatible with Schola

Mixing and matching fonts: sans-serif vs. serif

- Experiment: Exchanging sans-serif fonts?

TG Pagella (Lato)	Hamburgefons <i>Hamburgefons</i> Hamburgefons	ΑΒΓΧΨΩ αβγχψω <i>ΑΒΓΧΨΩ αβγχψω</i> ΑΒΓΧΨΩ αβγχψω
TG Termes (Lato)	Hamburgefons <i>Hamburgefons</i> Hamburgefons	ΑΒΓΧΨΩ αβγχψω <i>ΑΒΓΧΨΩ αβγχψω</i> ΑΒΓΧΨΩ αβγχψω
TG Bonum (DejaVu)	Hamburgefons <i>Hamburgefons</i> Hamburgefons	ΑΒΓΧΨΩ αβγχψω <i>ΑΒΓΧΨΩ αβγχψω</i> ΑΒΓΧΨΩ αβγχψω
TG Schola (TG Heros)	Hamburgefons <i>Hamburgefons</i> Hamburgefons	ΑΒΓΧΨΩ αβγχψω <i>ΑΒΓΧΨΩ αβγχψω</i> ΑΒΓΧΨΩ αβγχψω

Mixing and matching fonts: sans-serif vs. serif

- Experiment: Exchanging sans-serif fonts
 - Termes, Pagella with Lato (from Schola), scaled down
 - Bonum with DejaVu Sans (from Pagella), scaled up
 - Schola with Heros (from Termes), scaled up
- Some observations / Suggestions
 - visual shapes may be more compatible when exchanged
 - contrast in width, weight may be somewhat reduced
 - to some extent it may be just an optical illusion
 - just exchanging fonts doesn't work without rescaling

Testing the quality of math fonts

- Designing math fonts is complicated
 - lots of symbols and alphabets to be designed or assembled
 - lots of material from different sources to be combined
 - lots of parameters and glyph metrics to be adjusted
- Testing math fonts is also complicated
 - Checking the completeness of symbols and alphabets
 - Checking the design consistency of alphabets
 - Testing the spacing of individual glyphs (e.g. side-bearings)
 - Testing the placement of accents, superscripts, subscripts

 - It is easy to tell, if something looks wrong
 - It is not easy to tell how it should be right

Testing the spacing

- Some example test patterns (STIX Two Math)

<code>\mathup</code>	$ a + b + c + d + e + f + g + h + i + j +$
<code>\mathit</code>	$ a + b + c + d + e + f + g + h + i + j +$
<code>\mathbfup</code>	$ a + b + c + d + e + f + g + h + i + j +$
<code>\mathbfit</code>	$ a + b + c + d + e + f + g + h + i + j +$
<code>\mathbfsfup</code>	$ a + b + c + d + e + f + g + h + i + j +$
<code>\mathbfsfit</code>	$ a + b + c + d + e + f + g + h + i + j +$
<code>\mathup</code>	$ \alpha + \beta + \gamma + \delta + \epsilon + \zeta + \eta + \theta + \iota + \kappa +$
<code>\mathit</code>	$ \alpha + \beta + \gamma + \delta + \epsilon + \zeta + \eta + \theta + \iota + \kappa +$
<code>\mathbfup</code>	$ \alpha + \beta + \gamma + \delta + \epsilon + \zeta + \eta + \theta + \iota + \kappa +$
<code>\mathbfit</code>	$ \alpha + \beta + \gamma + \delta + \epsilon + \zeta + \eta + \theta + \iota + \kappa +$
<code>\mathbfsfup</code>	$ \alpha + \beta + \gamma + \delta + \epsilon + \zeta + \eta + \theta + \iota + \kappa +$
<code>\mathbfsfit</code>	$ \alpha + \beta + \gamma + \delta + \epsilon + \zeta + \eta + \theta + \iota + \kappa +$

Testing the accent placement

- Some example test patterns (STIX Two Math)

<code>\mathup</code>	$\hat{a} + \hat{b} + \hat{c} + \hat{d} + \hat{e} + \hat{f} + \hat{g} + \hat{h} + \hat{i} + \hat{j} + \hat{k} + \hat{l} + \hat{m} +$
<code>\mathit</code>	$\hat{a} + \hat{b} + \hat{c} + \hat{d} + \hat{e} + \hat{f} + \hat{g} + \hat{h} + \hat{i} + \hat{j} + \hat{k} + \hat{l} + \hat{m} +$
<code>\mathbfup</code>	$\hat{\mathbf{a}} + \hat{\mathbf{b}} + \hat{\mathbf{c}} + \hat{\mathbf{d}} + \hat{\mathbf{e}} + \hat{\mathbf{f}} + \hat{\mathbf{g}} + \hat{\mathbf{h}} + \hat{\mathbf{i}} + \hat{\mathbf{j}} + \hat{\mathbf{k}} + \hat{\mathbf{l}} + \hat{\mathbf{m}} +$
<code>\mathbfbit</code>	$\hat{\mathbf{a}} + \hat{\mathbf{b}} + \hat{\mathbf{c}} + \hat{\mathbf{d}} + \hat{\mathbf{e}} + \hat{\mathbf{f}} + \hat{\mathbf{g}} + \hat{\mathbf{h}} + \hat{\mathbf{i}} + \hat{\mathbf{j}} + \hat{\mathbf{k}} + \hat{\mathbf{l}} + \hat{\mathbf{m}} +$
<code>\mathbfsfup</code>	$\hat{\mathbf{a}} + \hat{\mathbf{b}} + \hat{\mathbf{c}} + \hat{\mathbf{d}} + \hat{\mathbf{e}} + \hat{\mathbf{f}} + \hat{\mathbf{g}} + \hat{\mathbf{h}} + \hat{\mathbf{i}} + \hat{\mathbf{j}} + \hat{\mathbf{k}} + \hat{\mathbf{l}} + \hat{\mathbf{m}} +$
<code>\mathbfsfbit</code>	$\hat{\mathbf{a}} + \hat{\mathbf{b}} + \hat{\mathbf{c}} + \hat{\mathbf{d}} + \hat{\mathbf{e}} + \hat{\mathbf{f}} + \hat{\mathbf{g}} + \hat{\mathbf{h}} + \hat{\mathbf{i}} + \hat{\mathbf{j}} + \hat{\mathbf{k}} + \hat{\mathbf{l}} + \hat{\mathbf{m}} +$
<code>\mathup</code>	$\hat{\alpha} + \hat{\beta} + \hat{\gamma} + \hat{\delta} + \hat{\epsilon} + \hat{\zeta} + \hat{\eta} + \hat{\theta} + \hat{i} + \hat{\kappa} + \hat{\lambda} + \hat{\mu} +$
<code>\mathit</code>	$\hat{\alpha} + \hat{\beta} + \hat{\gamma} + \hat{\delta} + \hat{\epsilon} + \hat{\zeta} + \hat{\eta} + \hat{\theta} + \hat{i} + \hat{\kappa} + \hat{\lambda} + \hat{\mu} +$
<code>\mathbfup</code>	$\hat{\mathbf{\alpha}} + \hat{\mathbf{\beta}} + \hat{\mathbf{\gamma}} + \hat{\mathbf{\delta}} + \hat{\mathbf{\epsilon}} + \hat{\mathbf{\zeta}} + \hat{\mathbf{\eta}} + \hat{\mathbf{\theta}} + \hat{\mathbf{i}} + \hat{\mathbf{\kappa}} + \hat{\mathbf{\lambda}} + \hat{\mathbf{\mu}} +$
<code>\mathbfbit</code>	$\hat{\mathbf{\alpha}} + \hat{\mathbf{\beta}} + \hat{\mathbf{\gamma}} + \hat{\mathbf{\delta}} + \hat{\mathbf{\epsilon}} + \hat{\mathbf{\zeta}} + \hat{\mathbf{\eta}} + \hat{\mathbf{\theta}} + \hat{\mathbf{i}} + \hat{\mathbf{\kappa}} + \hat{\mathbf{\lambda}} + \hat{\mathbf{\mu}} +$
<code>\mathbfsfup</code>	$\hat{\mathbf{\alpha}} + \hat{\mathbf{\beta}} + \hat{\mathbf{\gamma}} + \hat{\mathbf{\delta}} + \hat{\mathbf{\epsilon}} + \hat{\mathbf{\zeta}} + \hat{\mathbf{\eta}} + \hat{\mathbf{\theta}} + \hat{\mathbf{i}} + \hat{\mathbf{\kappa}} + \hat{\mathbf{\lambda}} + \hat{\mathbf{\mu}} +$
<code>\mathbfsfbit</code>	$\hat{\mathbf{\alpha}} + \hat{\mathbf{\beta}} + \hat{\mathbf{\gamma}} + \hat{\mathbf{\delta}} + \hat{\mathbf{\epsilon}} + \hat{\mathbf{\zeta}} + \hat{\mathbf{\eta}} + \hat{\mathbf{\theta}} + \hat{\mathbf{i}} + \hat{\mathbf{\kappa}} + \hat{\mathbf{\lambda}} + \hat{\mathbf{\mu}} +$

Testing the superscript placement

- Some example test patterns (STIX Two Math)

<code>\mathup</code>	$a^2 + b^2 + c^2 + d^2 + e^2 + f^2 + g^2 + h^2 + i^2 + j^2 +$
<code>\mathit</code>	$a^2 + b^2 + c^2 + d^2 + e^2 + f^2 + g^2 + h^2 + i^2 + j^2 +$
<code>\mathbfup</code>	$\mathbf{a}^2 + \mathbf{b}^2 + \mathbf{c}^2 + \mathbf{d}^2 + \mathbf{e}^2 + \mathbf{f}^2 + \mathbf{g}^2 + \mathbf{h}^2 + \mathbf{i}^2 + \mathbf{j}^2 +$
<code>\mathbfbit</code>	$\mathbf{a}^2 + \mathbf{b}^2 + \mathbf{c}^2 + \mathbf{d}^2 + \mathbf{e}^2 + \mathbf{f}^2 + \mathbf{g}^2 + \mathbf{h}^2 + \mathbf{i}^2 + \mathbf{j}^2 +$
<code>\mathbfbfsfup</code>	$\mathbf{a}^2 + \mathbf{b}^2 + \mathbf{c}^2 + \mathbf{d}^2 + \mathbf{e}^2 + \mathbf{f}^2 + \mathbf{g}^2 + \mathbf{h}^2 + \mathbf{i}^2 + \mathbf{j}^2 +$
<code>\mathbfbfsfit</code>	$\mathbf{a}^2 + \mathbf{b}^2 + \mathbf{c}^2 + \mathbf{d}^2 + \mathbf{e}^2 + \mathbf{f}^2 + \mathbf{g}^2 + \mathbf{h}^2 + \mathbf{i}^2 + \mathbf{j}^2 +$
<code>\mathup</code>	$\alpha^2 + \beta^2 + \gamma^2 + \delta^2 + \epsilon^2 + \zeta^2 + \eta^2 + \theta^2 + \iota^2 + \kappa^2 +$
<code>\mathit</code>	$\alpha^2 + \beta^2 + \gamma^2 + \delta^2 + \epsilon^2 + \zeta^2 + \eta^2 + \theta^2 + \iota^2 + \kappa^2 +$
<code>\mathbfup</code>	$\mathbf{\alpha}^2 + \mathbf{\beta}^2 + \mathbf{\gamma}^2 + \mathbf{\delta}^2 + \mathbf{\epsilon}^2 + \mathbf{\zeta}^2 + \mathbf{\eta}^2 + \mathbf{\theta}^2 + \mathbf{\iota}^2 + \mathbf{\kappa}^2 +$
<code>\mathbfbit</code>	$\mathbf{\alpha}^2 + \mathbf{\beta}^2 + \mathbf{\gamma}^2 + \mathbf{\delta}^2 + \mathbf{\epsilon}^2 + \mathbf{\zeta}^2 + \mathbf{\eta}^2 + \mathbf{\theta}^2 + \mathbf{\iota}^2 + \mathbf{\kappa}^2 +$
<code>\mathbfbfsfup</code>	$\mathbf{\alpha}^2 + \mathbf{\beta}^2 + \mathbf{\gamma}^2 + \mathbf{\delta}^2 + \mathbf{\epsilon}^2 + \mathbf{\zeta}^2 + \mathbf{\eta}^2 + \mathbf{\theta}^2 + \mathbf{\iota}^2 + \mathbf{\kappa}^2 +$
<code>\mathbfbfsfit</code>	$\mathbf{\alpha}^2 + \mathbf{\beta}^2 + \mathbf{\gamma}^2 + \mathbf{\delta}^2 + \mathbf{\epsilon}^2 + \mathbf{\zeta}^2 + \mathbf{\eta}^2 + \mathbf{\theta}^2 + \mathbf{\iota}^2 + \mathbf{\kappa}^2 +$

Testing the subscript placement

- Some example test patterns (STIX Two Math)

<code>\mathup</code>	$a_0 + b_0 + c_0 + d_0 + e_0 + f_0 + g_0 + h_0 + i_0 + j_0 +$
<code>\mathit</code>	$a_0 + b_0 + c_0 + d_0 + e_0 + f_0 + g_0 + h_0 + i_0 + j_0 +$
<code>\mathbfup</code>	$\mathbf{a}_0 + \mathbf{b}_0 + \mathbf{c}_0 + \mathbf{d}_0 + \mathbf{e}_0 + \mathbf{f}_0 + \mathbf{g}_0 + \mathbf{h}_0 + \mathbf{i}_0 + \mathbf{j}_0 +$
<code>\mathbfbit</code>	$\mathbf{a}_0 + \mathbf{b}_0 + \mathbf{c}_0 + \mathbf{d}_0 + \mathbf{e}_0 + \mathbf{f}_0 + \mathbf{g}_0 + \mathbf{h}_0 + \mathbf{i}_0 + \mathbf{j}_0 +$
<code>\mathbfbfsfup</code>	$\mathbf{a}_0 + \mathbf{b}_0 + \mathbf{c}_0 + \mathbf{d}_0 + \mathbf{e}_0 + \mathbf{f}_0 + \mathbf{g}_0 + \mathbf{h}_0 + \mathbf{i}_0 + \mathbf{j}_0 +$
<code>\mathbfbfsfit</code>	$\mathbf{a}_0 + \mathbf{b}_0 + \mathbf{c}_0 + \mathbf{d}_0 + \mathbf{e}_0 + \mathbf{f}_0 + \mathbf{g}_0 + \mathbf{h}_0 + \mathbf{i}_0 + \mathbf{j}_0 +$
<code>\mathup</code>	$\alpha_0 + \beta_0 + \gamma_0 + \delta_0 + \epsilon_0 + \zeta_0 + \eta_0 + \theta_0 + \iota_0 + \kappa_0 +$
<code>\mathit</code>	$\alpha_0 + \beta_0 + \gamma_0 + \delta_0 + \epsilon_0 + \zeta_0 + \eta_0 + \theta_0 + \iota_0 + \kappa_0 +$
<code>\mathbfup</code>	$\mathbf{\alpha}_0 + \mathbf{\beta}_0 + \mathbf{\gamma}_0 + \mathbf{\delta}_0 + \mathbf{\epsilon}_0 + \mathbf{\zeta}_0 + \mathbf{\eta}_0 + \mathbf{\theta}_0 + \mathbf{\iota}_0 + \mathbf{\kappa}_0 +$
<code>\mathbfbit</code>	$\mathbf{\alpha}_0 + \mathbf{\beta}_0 + \mathbf{\gamma}_0 + \mathbf{\delta}_0 + \mathbf{\epsilon}_0 + \mathbf{\zeta}_0 + \mathbf{\eta}_0 + \mathbf{\theta}_0 + \mathbf{\iota}_0 + \mathbf{\kappa}_0 +$
<code>\mathbfbfsfup</code>	$\mathbf{\alpha}_0 + \mathbf{\beta}_0 + \mathbf{\gamma}_0 + \mathbf{\delta}_0 + \mathbf{\epsilon}_0 + \mathbf{\zeta}_0 + \mathbf{\eta}_0 + \mathbf{\theta}_0 + \mathbf{\iota}_0 + \mathbf{\kappa}_0 +$
<code>\mathbfbfsfit</code>	$\mathbf{\alpha}_0 + \mathbf{\beta}_0 + \mathbf{\gamma}_0 + \mathbf{\delta}_0 + \mathbf{\epsilon}_0 + \mathbf{\zeta}_0 + \mathbf{\eta}_0 + \mathbf{\theta}_0 + \mathbf{\iota}_0 + \mathbf{\kappa}_0 +$

Testing the quality of math fonts

- Some observations:
 - Testing the spacing needs to be done for all alphabets
 - Spacing of math may need to be different from text
 - Default text spacing may be too tight for math
 - some letters are notoriously difficult, e.g. f , g , j , β , ζ , ξ , θ
- How good are existing fonts? (T_EX Gyre)
 - latest TG Schola already has a little more spacing
 - earlier TG fonts may have some problematic spacing
- How good are other recent additions?
 - STIX Two Math has incorrect metrics in bold sans serif

Summary and Conclusions

- Where are we?
 - OpenType math font technology established for 10 years
 - OpenType math fonts provide many advantages to users
 - OpenType math fonts pose challenges to developers
- How are we doing?
 - Choices of OpenType math fonts have grown every year
 - LM/TG is doing well in symbol completeness
 - LM/TG is nearly complete in math alphabets
- What remains to be done?
 - Choices of sans-serif fonts may need to be reconsidered
 - Spacing and positioning may need to be checked/improved
 - another round of revisions to each fonts may be needed
 - lots of testing remains to be done for each revision