#### Scripting the Internet of Things $\nabla \cdot \mathbf{B} = 0 \ \nabla \times \mathbf{E} = -\partial \mathbf{B} / \partial t$

 $= \mu J + 1/c^2 \partial E / \partial t F = q (E + v \times B) - \hbar^2 / 2m \nabla^2 \psi$ 

 $- \max \mathbf{F} = GMmr/r^3 \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$ 

 $dx^{2} dx^{2} = g_{\mu\nu} dx^{\mu} dx^{\nu} g_{\mu\nu} (dx^{\mu}/d\tau) (dx^{\nu}/d\tau) = 1 \Gamma_{\mu\nu\sigma} = 1/2 (g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$ 

 $c^2 \partial \mathbb{E} / \partial t = a (\mathbb{E} + \mathbf{y} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi(\mathbf{x}, t) + V(\mathbf{x}) \psi(\mathbf{x}, t) = E \psi(\mathbf{x}, t) \mathbf{x}' = \gamma (\mathbf{x} - \mathbf{y} t) \mathbf{t}' = \gamma (t - \mathbf{y} t)$  $0 E_i = -1/c\partial A_i/\partial t - \partial_i \phi B_i = \epsilon_{ijk}\partial_j A_k F^{\mu\nu} = \partial^{\mu}A^{\nu} - \partial^{\nu}A^{\mu} \tilde{F}^{\mu\nu} = 1/2\epsilon^{\mu}$  $+ \Gamma^{\alpha}_{\nu\sigma}\Gamma^{\mu}_{\alpha\rho} - \Gamma^{\alpha}_{\nu\rho}\Gamma^{\mu}_{\alpha\sigma} R_{\mu\nu} = R^{\rho}_{\mu\nu\rho} R = R^{\mu}_{\mu} G_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu}R = 0$ 

#### Damien P. George

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# PyCon AU, Melbourne, 12th August 2016

 $|\psi(t)\rangle \langle x \rangle = \langle \psi | x | \psi \rangle \Delta x \Delta p \ge \hbar/2 \ p_i = -i\hbar \partial_i \ E = i\hbar \partial/\partial t \ H = p^2/2m + V$  $v(t) t' = \gamma(t - vx/c^2) \gamma = 1/(1 - v^2/c^2)^{1/2} x' = -t \sinh \xi + x \cosh \xi t' = t \cosh \xi - x \sinh \xi t_0$  $= 1/2 \epsilon^{\mu\nu\rho\sigma} F_{\rho\sigma} \partial_{\nu} F^{\mu\nu} = J^{\nu} \partial_{\nu} \tilde{F}^{\mu\nu} = 0 ds^2 = c^2 dt^2 - dx^2 - dy^2 - dz^2 ds^2 = g_{\mu\nu} dx^{\mu} dx^{\nu} g_{\mu\nu}$  $8\pi G T_{\mu\nu} ds^2 = (1 - 2GM/r)dt^2 - dr^2/(1 - 2GM/r) - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 \Delta \nu \approx$  $|a\rangle = E |a\rangle U = e^{Ht/i\hbar} \mathbf{F} = m\mathbf{a} \mathbf{F} = GMm\mathbf{r}/r^3 \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$  $\xi \tanh \xi = v/c \cosh \xi = \gamma L = L_0/\gamma T = \gamma T_0 u' = (u - v)/(1 - uv/c^2) p = \gamma mv$  $= g_{\mu\nu} dx^{\mu} dx^{\nu} g_{\mu\nu} (dx^{\mu}/d\tau) (dx^{\nu}/d\tau) = 1 \Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$ TOTAL MULTINALIA  $\mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t \nabla \times \mathbf{B} = \mu \mathbf{J} + 1/c^2 \partial \mathbf{E}/\partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2/2m\nabla^2 \psi$  $v/c \cosh \xi = \gamma L = L_0/\gamma T = \gamma T_0 u$  $(u - v)/(1 - uv/c^2) p = \gamma m v E = \gamma m c^2 E^2 = p^2 c^2 + m^2 c^4 \partial_\mu J^\mu = 0 E_i = -1/c \partial A_i$  $= g_{\mu\nu} \mathrm{d} x^{\mu} \mathrm{d} x^{\nu} \ g_{\mu\nu} (\mathrm{d} x^{\mu}/\mathrm{d} \tau) (\mathrm{d} x^{\nu}/\mathrm{d} \tau) = 1 \ \Gamma_{\mu\nu\sigma} = 1/2 (g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu}) \ \mathrm{d} v^{\mu}/\mathrm{d} s + \Gamma^{\mu}_{\nu\sigma} v^{\nu} v^{\sigma} = 0 \ R^{\mu}_{\nu\rho\sigma} = \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma} (\mathrm{d} x^{\mu}/\mathrm{d} \tau) = 0 \ \mathrm{d} v^{\mu}/\mathrm{d} s + \Gamma^{\mu}_{\nu\sigma} v^{\mu}/\mathrm{d} s + \Gamma^{\mu}_{\sigma} v^{\mu}$  $\delta^{2} - r^{2} \sin^{2} \theta d\phi^{2} \Delta v \approx v_{s} GM(1/r_{s} - 1/r_{s}) d^{2}u/d\phi^{2} + u - GM/A^{2} - 3GMu^{2} = 0 \delta = 2GM/R \left[\psi^{*}\psi dx = 1 P(x, t) = |\psi(x, t)|^{2} \psi(x, t) = |\psi(x,$  $\mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B} / \partial t \nabla \times \mathbf{B} = \mu \mathbf{J} + 1/c^2 \partial \mathbf{E} / \partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi(\mathbf{x}, t) + V(\mathbf{x}) \psi(\mathbf{x}, t) = E \psi(\mathbf{x}, t) \mathbf{x}' = \gamma(\mathbf{x} - \mathbf{v}t) \mathbf{t}' = \gamma(t - \mathbf{v}t) \mathbf{x}' =$  $wv/c^2) \ p = \gamma mv \ E = \gamma mc^2 \ E^2 = p^2 c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_i = -1/c \partial A_i / \partial t - \partial_i \phi \ B_i = \epsilon_{ijk} \partial_j A_k \ F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu \ \bar{F}^{\mu\nu} = 1/2 \epsilon^{\mu i} / 2 \epsilon^{\mu i}$  $_{\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu}) \ \mathrm{d} v^{\mu}/\mathrm{d} s + \Gamma^{\mu}_{\nu\sigma} v^{\nu} v^{\sigma} = 0 \ R^{\mu}_{\nu\rho,\sigma} - \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma} \Gamma^{\mu}_{\mu\rho} - \Gamma^{\alpha}_{\nu\rho} \Gamma^{\mu}_{\alpha\sigma} R_{\mu\nu} = R^{\rho}_{\mu\nu\rho} R = R^{\mu}_{\mu} \ g_{\mu\nu} = R_{\mu\nu} - 1/2 g_{\mu\nu} R = 0 \ R^{\mu}_{\mu\nu} = R^{\mu}_{\mu\nu} R_{\mu\nu} = R^{\mu$  $+ u - GM/A^2 - 3GMu^2 = 0 \ \delta = 2GM/R \ \int \psi^* \psi dx = 1 \ P(x,t) = |\psi(x,t)|^2 \ \psi(x,t) = |\psi(t)\rangle \ \langle x \rangle = \langle \psi | x | \psi \rangle \ \Delta x \Delta p \ge \hbar/2 \ p_i = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = p_i \ A = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_i \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial/\partial t \ H$  $\mu J + 1/c^2 \partial E/\partial (E - v(E + v \times B) - h^2/2m\nabla^2 \psi(x, t) + V(x)\psi(x, t) = E\psi(x, t) x' = \gamma(x - vt) t' = \gamma(t - vx/c^2) \gamma = 1/(1 - v^2/c^2)^{1/2} x' = -t \sinh \xi + x \cosh \xi t' = 0$ 

# The Internet of Things?

#### IoT = Microcontrollers + wireless communications



- lighting: homes and office buildings
- heating and cooling houses
- traffic monitoring: sensors in/above roads
- farming: water levels, livestock tracking
- logistics: real-time tracking of shipping containers

 $|\psi(x,t)|^2 |\psi(x,t) = |\psi(t)\rangle \langle x \rangle = \langle \psi | x | \psi \rangle \Delta x \Delta p \ge \hbar/2 p_i = -i\hbar \partial_i E = i\hbar \partial/\partial t H = p^2/2m + V$ 

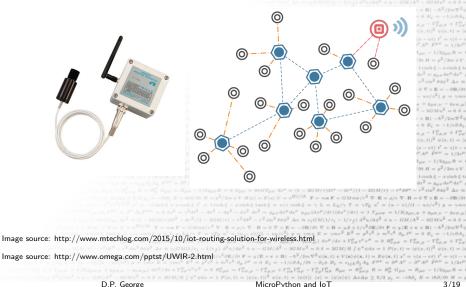
 $c^2 \partial \mathbf{E} / \partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi$ 

 $(1/r)dt^2 = dr^2/(1 - 2GM/r) = r^2 d\theta^2 = r^2 \sin^2 \theta d\phi^2 \Delta \nu \approx$ 

$$\begin{split} & V(B)(n-E(n)) = -E(n) (T - \frac{d^2 t^{1/3}}{n} - F - nn F - CMm(r)^{-3} \nabla E = \rho t \nabla \mathbf{E} - \sigma \mathbf{D} \nabla \mathbf{E} - \frac{d}{2} - \frac{d}{2} \mathbf{D} \right) \mathbf{p} - \gamma \mathbf{n} \mathbf{v} \\ & = 0 + t \operatorname{int} \mathbf{L} + n \mathbf{L} - r + t - E_0 t (T - \tau \tau \mathbf{D} + \mathbf{v} - \mathbf{L} - r + r + \tau \mathbf{D} + \mathbf{L} - \mathbf{L} - r + \tau \mathbf{D} + \mathbf{L} - \mathbf{L} - r + \tau \mathbf{D} + \mathbf{L} - \mathbf{L} - r + \tau \mathbf{D} + \mathbf{L} - \mathbf{L} -$$

# End Nodes

The end nodes are the fingertips: sensors and actuators.

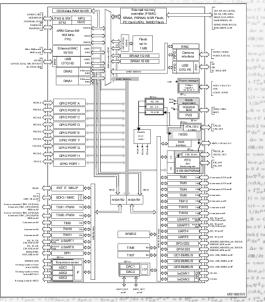


#### $\psi(\mathbf{x}, t) = E \psi(\mathbf{x}, t) \ \mathbf{x}' = \gamma (\mathbf{x} - \mathbf{v}t) \ \mathbf{t}' = \gamma (t - \mathbf{v}\mathbf{x}/\mathbf{c})$ = $s_{ijk} \partial_j A_k \ F^{\mu\nu} = \partial^{\mu} A^{\nu} - \partial^{\nu} A^{\mu} \ F^{\mu\nu} = 1/2\epsilon^{\mu t}$



High-level scripting languages allow:

- easier to read/write code
- abstraction of HW
- rapid prototyping
- more portable code
- library reuse



$$\begin{split} & 30!(\psi - e^2 \sin^2 \omega - e^2 \sin^2 d_0)^2 \, d_0 = u_1 (2M) (\ell_1 - 1/\epsilon_2) \, d_0^2 / (d_0^2 + \omega - 2M) (d_0^2 - 3M)^2 = 0 \, \delta = 2M/R \, \left[ e^{\psi} e^{d_0} + a = [e(\epsilon_1)^2 - e(\epsilon_1) - e(\epsilon_1)^2 - e(\epsilon_1) + e(\epsilon_1)^2 - e(\epsilon_1) - e(\epsilon_1)^2 - e(\epsilon_1) + e$$

$$\begin{split} & \pi_1 = \pi_{ijk} \sigma_j A_k \ F^{\mu\nu} = \partial^{\mu} A^{\nu} - \partial^{\nu} A^{\mu} \ F^{\mu\nu} = 1 \\ & \pi_{\mu\nu\rho} = \pi_{\mu\nu\rho}^{\rho} R = \pi_{\mu}^{\mu} \ G_{\mu\nu} = \pi_{\mu\nu} - 1/2g_{\mu\nu} I \\ & \Delta \pi \Delta p \ge \hbar/2 \ p_1 = -i\hbar \partial_1 E = i\hbar \partial/\partial t \ H = p^2/2m \end{split}$$

## Lua and eLua

#### www.lua.org

#### www.eluaproject.net

 $E(\rho) U = \rho^{Ht/1h}$ ,  $F = ma F = GMmr/r^3 \nabla \cdot E = \rho/\epsilon \nabla \cdot B = 0 \nabla \times E$ 

 $^{2} dx^{2} = g_{\mu\nu} dx^{\mu} dx^{\nu} g_{\mu\nu} (dx^{\mu}/d\tau) (dx^{\nu}/d\tau) = 1 \Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$ 



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about

Lua 5.3.3 released Programando em Lua published

Lua Workshop 2016 to be held in San Francisco



$$\begin{split} & \mu \sigma, \nu - g \nu \sigma, \mu) \\ & & \bigoplus _{i=1}^{N} M_{i} u^{2} = 0 \ \delta \\ & & \bigoplus _{i=1}^{N} (2M_{i} u^{2} - 1) (2M_{i$$

013 / 04

function factorial(n)
 local x = 1
 for i = 2, n do
 x = x \* i
 end
 return x
end

gpio.mode(1, gpio.OUTPUT)

gpio.write(1, gpio.HIGH)

 1
 Pros: simple language, light-weight, fast

 \* i
 Cons: simple language, no native bitwise ops, no integers (recently fixed!, eLua yet to catch up)

 pio.OUTPUT)
 Uses in IoT: NodeMCU ESP8266 board

D.P. George

MicroPython and IoT

 $u = GM/A^2 - 3GMu^2 = 0 \ \delta = 2GM/R \ \int \psi^* \psi \, \mathrm{d}x = 1 \ P(x,t) = |\psi(x,t)|^2 \ \psi(x,t) = |\psi(t)\rangle \ \langle x \rangle = \langle \psi | x | \psi \rangle \ \Delta x \Delta p \ge \hbar/2 \ p_4 = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = p_4 \ A = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ E = -i\hbar\partial/\partial t \ H =$ 

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# JavaScript

#### www.espruino.org, jerryscript.net, www.tessel.io, duktape.org



 $r^{\mu} = dy^{\mu} = dx^{\mu} dx^{\mu}$   $r^{\mu}dt^{\nu} = dr^{\mu}/(1 - 2GM/r) - r^{2}d\theta^{2} - mx F = GMmr/r^{3} \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{1}$  $L = L_{0}/\gamma T = \gamma T_{0} u^{\prime} = (u - v)/\epsilon$ 



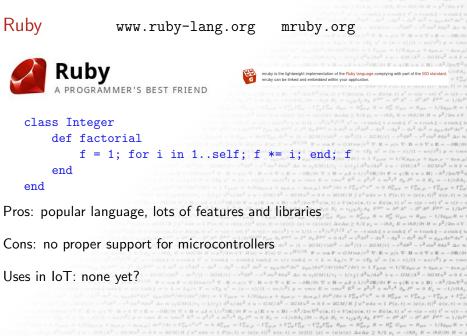
JerryScript: JavaScript engine for the Internet of Things



 $\begin{aligned} & : \nabla \mu_{\mu\nu} = R_{\mu\nu} - 1/3g_{\mu\nu}R = 0 \\ & : E = h\delta/0\, h = p^2/2m + V \ i \\ \cosh \xi \ i' = t \cosh \xi - x \sinh \xi \ i \\ h = 0 \\ \sin^2 - dx^2 dx^2 = g_{\mu\nu}dx^4 dx^{\mu} \\ \sin^2 - dx^2 dx^2 = g_{\mu\nu}dx^4 dx^{\mu} \\ \sin^2 (x - B) = 0 \ \nabla \times \mathbf{E} = -\partial \mathbf{B}/dt \\ a - v/(1 - uv/c^3) \\ p = mv/c^3 \\ a - v/(2 - uv/c^3) \\ mv/c^3 \\ mv/c^3$ 

 $+ \mathbf{v} \times \mathbf{B} = \hbar^2 / 2m \nabla^2 \psi$ 

setInterval(function() {
 digitalWrite(LED1, Math.random()>0.5);
}, 20);
Pros: very popular language, large community, simple but powerful
Cons: some crazy semantics, callback-based, all numbers are floats
Uses in IoT: Espruino boards, ESP8266, Tessel boards, ...



# Python™

#### Is it possible to put Python on a microcontroller?

#### Why is it hard?

 Very little memory (RAM, ROM) on a microcontroller.

### Motivation for using Python:

- High-level language with powerful features (classes, list comprehension, generators, exceptions, ...) and libraries. DE/DIF  $\mathbf{E} + \mathbf{v} \times \mathbf{B} = \hbar^2 / 2m \nabla^2 \psi$
- Large existing community.
- Very easy to learn, powerful for advanced users:  $\nu \rho \sigma F_{\rho \sigma} \partial_{\nu} F^{\mu \nu} = J^{\nu} \partial_{\nu} \tilde{F}^{\mu \nu} = 0 ds^{2} = c^{2} dt^{2} - dx^{2} - dy^{2} - dz^{2} ds^{2} = g_{\mu \nu} dx^{\mu} dx^{\nu} dx^{\nu}$ learning curve.  $0 \ G_{\mu\nu} = 8\pi G T_{\mu\nu} \ ds^2 = (1 - 2GM/r) dt^2 - dr^2/(1 - 2GM/r) - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 \ \Delta\nu \approx 0$  $\mathbf{F} = m\mathbf{a} \, \mathbf{F} = GMm\mathbf{r}/r^3 \, \nabla \cdot \mathbf{E} = \rho/\epsilon$
- Ideal for microcontrollers: native bitwise operations, procedura  $M(1/r_i - 1/r_f) d^2u/d\phi^2 + u - GM/A^2 - 3GMu^2$ code, distinction between int and float, robust exceptions.
- Lots of opportunities for optimisation (Python is compiled).  $dv^{\mu}/ds + \Gamma^{\mu}_{\nu\sigma}v^{\nu}v^{\sigma} = 0 R^{\mu}_{\nu\sigma\sigma} = \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\sigma}$  $\partial_{\mu}J^{\mu} = 0 E_i = -1/c\partial A_i/\partial t - \partial_i \phi B_i = \epsilon_{ijk}\partial_j A_k F^{\mu}$

 $= 0 R^{\mu}_{\nu\rho\sigma} = \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma}\Gamma^{\mu}_{\alpha\rho} - \Gamma^{\alpha}_{\nu\rho}\Gamma^{\mu}_{\alpha\sigma} R_{\mu\nu} = R^{\rho}_{\mu\nu\rho} R = R^{\mu}_{\mu} G_{\mu\nu} = R_{\mu\nu}$ 

 $\mathbf{F} = \max \mathbf{F} = GMmr/r^3 \nabla \cdot \mathbf{E} = o/r \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$ 

 $(\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi(\mathbf{x}, t) + V(\mathbf{x}) \psi(\mathbf{x}, t) = E \psi(\mathbf{x}, t) \ \mathbf{x}' = \gamma (\mathbf{x} - \mathbf{v}t) \ \mathbf{t}' = \gamma (\mathbf{t} - \mathbf{v})$ 

# Why can't we use CPython? (or PyPy?)

Integer operations:

Integer object (max 30 bits): 4 words (16 bytes) Preallocates 257+5=262 ints  $\longrightarrow$  4k RAM! Could ROM them, but that's still 4k ROM. And each integer outside the preallocated ones would be another 16 bytes.

Method calls:

led.on(): creates a bound-method object, 5 words (20 bytes) led.intensity(1000)  $\longrightarrow$  36 bytes RAM!

For loops: require heap to allocate a range iterator.

 $+ \frac{1}{c^2} \partial \mathbb{E} / \partial t = o \left( \mathbb{E} + \mathbf{y} \times \mathbb{B} \right) - \frac{\hbar^2}{2m} \nabla^2 \psi(\mathbf{x}, t) + V(\mathbf{x}) \psi(\mathbf{x}, t) = E \psi(\mathbf{x}, t) \mathbf{x}^t = \gamma (\mathbf{x} - \mathbf{y} t) \mathbf{t}^t = \gamma (\mathbf{x} - \mathbf{y} t) \mathbf{t}^t$ 

 $\nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$ 

 $\mathbf{B} = \mu \mathbf{J} + 1/c^2 \partial \mathbf{E} / \partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi$ 

# MicroPython: Python for microcontrollers

(and embedded systems, constrained environments, IoT, ...)

 $\begin{aligned} & (1 + 1) + u_{1}(r) = r + r_{1}u_{1}^{-1} = (-r) + r_{1}(r) + u_{1}(r) + r_{2}(r) +$ 

 $\Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu}) dv^{\mu}/ds + \Gamma_{\mu\sigma}^{\mu}v^{\nu}v^{\sigma} = 0 R_{\mu\rho\sigma}^{\mu} = \Gamma_{\nu\sigma,\rho}^{\mu} - \Gamma_{\nu\rho,\sigma}^{\mu} + \Gamma_{\nu\sigma}^{\mu} \Gamma_{\mu\rho}^{\mu} - \Gamma_{\mu\rho}^{\alpha} \Gamma_{\mu\sigma}^{\mu} R_{\mu\nu} = R_{\mu\nu\rho}^{\mu} R = R_{\mu\nu}^{\mu} R_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu} R = 0$   $d^{2}u/d\delta^{2} + u - GM/\lambda^{2} - 3GMu^{2} = 0 \delta = 2GM/R \int \psi^{\sigma} \psi dx = 1 P(x, t) = |\psi(x, t)|^{2} \psi(x, t) = |\psi(t)\rangle \langle x \rangle = \langle \psi|x|\psi \rangle \Delta x \Delta y \ge h/2 p_{4} = -h\delta_{4} E = i\hbar\delta/\delta t H = p_{4}$ 

 $ma F = GMmr/r^3 \nabla \cdot E = \rho/\epsilon \nabla \cdot B = 0 \nabla \times E = -\partial B/\partial t$ 

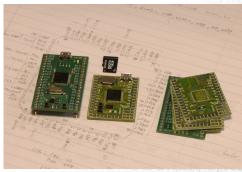
 $\partial \mathbf{B}/\partial t \nabla \times \mathbf{B} = \mu \mathbf{J} + 1/c^2 \partial \mathbf{E}/\partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2/2m\nabla^2 \psi$ 

 $\delta g^2 + dx^2 - dy^2 - dx^2 - dx^2 - g_{\mu\nu}dx^{\mu}dx^{\nu} - g_{\mu\nu}(dx^{\mu}/dx)(dx^{\mu}/dx) = 1 \Gamma_{\mu\nu\sigma} - 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$   $e^2/(1 - 2(MIT)) = e^2 dx^2 - e^2 \sin^2 \delta dx^2 - \Delta x = e_0 M(1/T_e - 1)r_F) d^2 u/de^2 + a - GM/A^2 - 2GM^2 = 0$  $\delta = 0 M(x)e^{-2} \nabla x = e_0 X + C = 0 = 0 = x = e^{-2} - 0 M(2 - X = e^{-2}) = e^{-2} - C = e^{-2} + e^{-2} - C = e^{-2} + e^{-2} - C = e^{-2} + e$ 

# Crowdfunding via Kickstarter

Kickstarter is a good way to see if your idea has traction, or not.

- 30th April 2013: start!
- 17th September: flashing LED with button in bytecode Python.
- 21st October: REPL, filesystem, USB VCP and MSD on PYBv2.



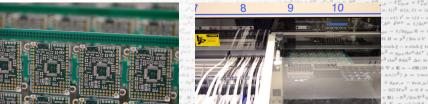
1 weekend to make the video. Kickstarter launched on 13 November 2013, ran for 30 days. Total backers: 1,931 Total raised: £97,803 (\$180k) Officially finished 12 April 2015.

 $1 \pm 1/c^2 \partial E/\partial t F = a (E \pm y \times B) - \hbar^2/2m\nabla^2 \psi$ 

# Manufacturing

#### Jaltek Systems, Luton UK — manufactured 13,000+ boards.





 $(d\tau) = 1 \Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu}) dv^{\mu}/ds + \Gamma^{\mu}_{\nu\sigma}v^{\nu}v^{\sigma} = 0 R^{\mu}_{\nu\rho\sigma} = \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma}$  $\frac{2}{r} = r^2 \sin^2 \theta d\phi^2 \Delta \psi \approx \psi_r GM(1/r_r - 1/r_r) \frac{d^2 u}{d\phi^2} + u - GM/A^2 - 3GMu^2 = 0 \delta = 2GM/R \left[\psi^* \psi dx = 1 P(x, t) = |\psi(x, t)|^2 \psi(x, t) = |$  $\mathbf{E} = -\partial \mathbf{B}/\partial t \nabla \mathbf{X} \mathbf{B} = \mu \mathbf{J} + 1/c^2 \partial \mathbf{E}/\partial t \mathbf{F} = q \left( \mathbf{E} + \mathbf{y} \times \mathbf{B} \right) - \hbar^2/2m \nabla^2 \psi(\mathbf{x}, t) + V(\mathbf{x})\psi(\mathbf{x}, t) = E\psi(\mathbf{x}, t) \mathbf{x}' = \gamma(x - vt) \mathbf{t}' = \gamma(t - vt) \mathbf{x}' + \frac{1}{2} \nabla^2 \psi(\mathbf{x}, t) \mathbf{x}' + \frac{1}{2} \nabla^2 \psi(\mathbf{x},$  $uv/c^2) p = \gamma mv E = \gamma mc^2 E^2 = p^2 c^2 + m^2 c^4 \partial_\mu J^\mu = 0 E_i = -1/c \partial A_i/\partial t - \partial_i \phi B_i = \epsilon_{ijk} \partial_j A_k F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu \tilde{F}^{\mu\nu} = 1/2\epsilon^{\mu} \partial_i A_i F^{\mu\nu} = 0$  $2(g_{\mu\nu,\sigma}+g_{\mu\sigma,\nu}-g_{\nu\sigma,\mu}) \ dv^{\mu}/dx + \Gamma^{\mu}_{\nu\sigma} v^{\nu} v^{\sigma} = 0 \ R^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\sigma,\rho} + \Gamma^{\alpha}_{\nu\sigma} \Gamma^{\mu}_{\alpha\rho} - \Gamma^{\mu}_{\nu\rho} \Gamma^{\mu}_{\alpha\sigma} R_{\mu\nu} = R^{\rho}_{\mu\nu\rho} R = R^{\mu}_{\mu} \ G_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu} R = 0 \ R^{\mu}_{\mu\nu} = R^{\mu}_{\mu\nu} R_{\mu\nu} R_{\mu\nu} = R^{\mu}_{\mu\nu} R_{\mu\nu} R_{\mu\nu}$  $u/d\phi^2 + u = GM/A^2 - 3GMu^2 = 0 \ \delta = 2GM/R \ \int \psi^* \psi dx = 1 \ P(x, t) = |\psi(x, t)|^2 \ \psi(x, t) = |\psi(t)\rangle \ \langle x \rangle = \langle \psi | x | \psi \rangle \ \Delta x \Delta p \ge h/2 \ p_4 = -ih\partial_4 \ E = ih\partial/\partial t \ H = p_4 \ A = -ih\partial_4 \ E = ih\partial/\partial t \ H = -ih\partial_4 \ A = -ih\partial_4$ 

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 $\nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B} / \partial t$ 

# It's all about the RAM

If you ask me 'why is it done that way?', I will most likely answer: 'to minimise RAM usage'.

- Interned strings, most already in ROM.
- Small integers stuffed in a pointer.
- Optimised method calls (thanks PyPy!).
- Range object is optimised (if possible).
- Python stack frames live on the C stack.
- ROM absolutely everything that can be ROMed!  $F_{\mu\sigma} \ \partial_{\nu} F^{\mu\nu} = J^{\nu} \ \partial_{\nu} \bar{F}^{\mu\nu} = 0 \ ds^2 = c^2 dt^2 - dx^2 - dy^2 - dz^2 \ ds^2 = g_{\mu\nu} dx^{\mu} dx^{\nu} dx^{\nu}$
- Garbage collection only (no reference counts).
- Exceptions implemented with custom set jmp/longjmp.  $-\max \mathbf{F} = GMmr/r^3 \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t \nabla \times \mathbf{B} = \mu \mathbf{J} + 1/c^2 \partial \mathbf{E}/\partial t \mathbf{F} = q \left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right) - \hbar^2/2m\nabla^2 \psi$

 $= v/c \cosh \xi = \gamma \ L = L_0 / \gamma \ T = \gamma T_0 \ u' = (u - v) / (1 - uv/c^2) \ p = \gamma mv \ E = \gamma mv^2 \ E^2 = p^2 c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1/c \partial A_4 / c^4 \ \partial_\mu J^\mu = 0 \ E_4 = -1$  $\mathrm{d} x^2 - \mathrm{d} x^2 - y_{\mu\nu} \mathrm{d} x^\mu \mathrm{d} x^\nu - g_{\mu\nu} \mathrm{d} x^\mu \mathrm{d} \tau ) (\mathrm{d} x^\mu / \mathrm{d} \tau) = 1 \ \Gamma_{\mu\nu\sigma} = 1/2 (g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu}) - \mathrm{d} v^\mu / \mathrm{d} x + \Gamma^\mu_{\mu\sigma} v^\nu v^\sigma = 0 \ R^\mu_{\nu\rho\sigma} = \Gamma^\mu_{\nu\sigma,\rho} - \Gamma^\mu_{\nu\rho,\sigma} + \Gamma^\sigma_{\nu\rho,\sigma} + \Gamma^\sigma_{\nu\sigma,\mu} + \Gamma^\sigma_{\nu\sigma$  $\theta^{2} = r^{2} \sin^{2} \theta d\phi^{2} \Delta v \approx v_{c} GM(1/r_{c} - 1/r_{c}) d^{2} u/d\phi^{2} + u - GM/A^{2} - 3GMu^{2} = 0 \delta = 2GM/R [\psi^{*}\psi dx = 1 P(x, t) = |\psi(x, t)|^{2} \psi(x, t) = |\psi(x,$  $\mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B} / \partial t \nabla \times \mathbf{B} = \mu \mathbf{J} + 1/c^2 \partial \mathbf{E} / \partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi(\mathbf{x}, t) + V(\mathbf{x}) \psi(\mathbf{x}, t) = E \psi(\mathbf{x}, t) \mathbf{x}' = \gamma(\mathbf{x} - \mathbf{v}t) \mathbf{t}' = \gamma(t - \mathbf{v}t) \mathbf{x}' =$  $= uv/c^2) \ p = \gamma mv \ E = \gamma mv^2 \ E^2 = p^2 c^2 + m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_i = -1/c \partial A_i / \partial t - \partial_i \phi \ B_i = \epsilon_{ijk} \partial_j A_k \ F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu \ \bar{F}^{\mu\nu} = 1/2 \epsilon^{\mu i} / 2 \epsilon^{\mu i$  $+ g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu}) d\nu^{\mu}/ds + \Gamma^{\mu}_{\mu\sigma} v^{\nu}v^{\sigma} = 0 R^{\mu}_{\nu\rho\sigma} = \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma} \Gamma^{\mu}_{\mu\rho} - \Gamma^{\alpha}_{\nu\rho} \Gamma^{\mu}_{\alpha\sigma} R_{\mu\nu} = R^{\mu}_{\mu\nu\rho} R = R^{\mu}_{\mu} G_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu}R = 0$ 

 $7Mmr/r^3 \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$ 

 $\mathbf{B} = \mu \mathbf{J} + 1/c^2 \partial \mathbf{E} / \partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi$ 

 $2GM/r)\mathrm{d}t^2 - \mathrm{d}r^2/(1 - 2GM/r) - r^2\mathrm{d}\theta^2 - r^2\sin^2\theta\mathrm{d}\phi^2 \Delta\nu \approx$  $\mathbf{F} = m\mathbf{a} \, \mathbf{F} = GMmr/r^3 \, \nabla \cdot \mathbf{E} = \rho/\epsilon \, \nabla \cdot \mathbf{B} = 0 \, \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$ 

 $g_{\mu\nu}(dx^{\mu}/d\tau)(dx^{\nu}/d\tau) = 1 \Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$  $\partial B/\partial t \nabla \times B = \mu J + 1/c^2 \partial E/\partial t F = g (E + \mathbf{v} \times B) - \hbar^2/2m\nabla^2 \psi$ 

 $E = \gamma m c^2 E^2 = p^2 c^2 + m^2 c^4 \partial_\mu J^\mu = 0 E_i = -1/c \partial A_i$ 

# GitHub and the open-source community

https://github.com/micropython

MicroPython is a *public* project on GitHub.

- A global coding conversation.
- Anyone can clone the code, make a fork, submit issues, make pull requests.

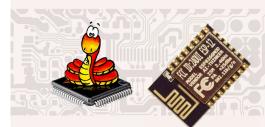
 $= R^{P}_{\mu\nu\rho} R = R^{P}_{\mu} G_{\mu\nu} = R_{\mu\nu} - 1/2g$ 

 $a \mathbf{F} = GMmr/r^3 \nabla \cdot \mathbf{E} = a/r \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -$ 

- MicroPython has over 3500 "stars" (top 0.02%), and more than 740 forks.
- Contributions come from many people (120+), with many different systems.
- Leads to: more robust code and build system, more features, more supported hardware.
- Hard to balance inviting atmosphere with strict code control.

A big project needs many contributors, and open-source allows such projects to exist.

## And then went back for more...



#### MicroPython on the ESP8266

 $1/c^2 \partial E/\partial t F = q (E + v \times B) - \hbar^2/2m\nabla^2 \psi$  $r/r^3 \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$  $= 1 \Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$  $1/c^2 \partial \mathbf{E} / \partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi$  $= p^2 c^2 + m^2 c^4 \partial_\mu J^\mu = 0 E_i = -1/c \partial A_i$ )  $A_{\nu} F^{\mu\nu} = \partial^{\mu}A^{\nu} - \partial^{\nu}A^{\mu} \tilde{F}^{\mu\nu} = 1/2\epsilon^{\mu\nu}$  $\Gamma^{\rho}_{\mu\nu\rho} R = R^{\mu}_{\mu} G_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu}R = 0$  $/2 p_i = -i\hbar \partial_i E = i\hbar \partial/\partial t H = p^2/2m + V$ 

Kickstarter #2 was a pure software	$\begin{split} & n = 0 \ g_{\mu\nu} = 8\pi G T_{\mu\mu} \ d^2 = (1 - 2GM/\gamma)d^2 - dr^2/(1 - 2GM) \\ & - 2Gm + 0 \ Hom \ Find \ T = M^{1/3} \ F = ma \ F = GM mar/r^3 \ \nabla \ E \\ & Campaign \ \gamma = coh \ \xi = \gamma \ L = L_0/\gamma \ T = \pi \ T_0 \ d^2 \\ & - dr^2 \ (dr^2) \ (dr^2/dr^2) \ dr^2 $	$= \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$ = $(u - v)/(1 - uv/c^2) p = \gamma mv$ $\sigma = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$
	.384 backers, £28,334 (\$50	${}^{t}\mathbf{F} = q \left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right) - \hbar^{2}/2m\nabla^{2}\psi$ ${}^{t}\mathbf{P}^{2}\mathbf{A}^{4} \partial_{\mu}J^{\mu} = 0 \ E_{i} = -1/c\partial A_{i}/c$ ${}^{t}\mathbf{A}^{\mu}_{\rho\sigma} = \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma}$
$\begin{split} & (1 + i) \left[ e^{-i} (x_1 - x_2 - x_1) + i \right] = e^{-i} (x_1 - x_1) = e^{-i} (x_1 - x_1) + i \\ & (1 + i) \left[ e^{-i} (x_1 - x_1) + i \right] = e^{-i} (x_1 - x_1) = e^{-i} (x_1 - x_1) + i \\ & (x_1 - x_1) + i \\ & (x_1 - x_1) + i \\ & (x_1 - x_1) = e^{-i} (x_1 - x_1) + i \\ & (x_1 - x_1) = e^{-i} (x_1 - x_1) + i \\ & (x_1 - x_1) + i \\ & (x_1 - x_1) = e^{-i} (x_1 - x_1) + i \\ & (x_1 - x_1) + i \\$	$(c^2 \partial E / \partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi(\mathbf{x}, t) + V(\mathbf{x}) \psi(\mathbf{x}, t) = E$ + $m^2 c^4 \ \partial_\mu J^\mu = 0 \ E_i = -1/c \partial A_i / \partial t - \partial_i \phi \ B_i = \epsilon_{ijk} \partial_j A_k \ F^{\mu\nu}$ $R^{\mu}_{\mu\rho\sigma} = \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\mu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma} \Gamma^{\alpha}_{\mu\rho} - \Gamma^{\alpha}_{\nu\rho} \Gamma^{\alpha}_{\mu\sigma} \ R_{\mu\nu} = R^{\rho}_{\mu\nu\rho} R =$	$ψ(\mathbf{x}, t) x' = γ(x - vt) t' = γ(t - v)$ = $∂^{μ} A^{ν} - ∂^{ν} A^{μ} \tilde{F}^{μν} = 1/2 ε^{μ}$ $R^{μ}_{μ} G_{μν} = R_{μν} - 1/2 g_{μν} R = 0$
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 $\partial B / \partial t \nabla \times B = \mu J + 1/c^2 \partial E / \partial t F = q (E + v \times B) - \hbar^2 / 2m \nabla^2 \psi$ Live Demo!  $=\rho^2/2m + V|B|a\rangle - E|a\rangle U = e^{Ht/i\hbar} \mathbf{F} = m\mathbf{a} \mathbf{F} = GMm\mathbf{r}/r^3 \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$  $dx^{2} - dy^{2} - dx^{2} - dx^{2} - dx^{2} - g_{\mu\nu}dx^{\mu}dx^{\nu} - g_{\mu\nu}(dx^{\mu}/d\tau)(dx^{\nu}/d\tau) = 1 \ \Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$  $GMmr/r^{3} \nabla \cdot \mathbf{E} = \rho/c \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t \nabla \times \mathbf{B} = \mu \mathbf{J} + 1/c^{2}\partial \mathbf{E}/\partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^{2}/2m\nabla^{2}\psi$  $T = \gamma T_0 \ u' = (u - v)/(1 - uv/c^2) \ p = \gamma mv \ E = \gamma mc^2 \ E^2 = p^2 c^2 + m^2 c^4 \ \partial_u J^{\mu} = 0 \ E_i = -1/c \partial A_i$  $B/\delta t \nabla \times B = \mu J + 1/c^2 \delta E/\delta t F = a(E + y \times B) - \hbar^2/2m \nabla^2 \psi(\mathbf{x}, t) + V(\mathbf{x})\psi(\mathbf{x}, t) = E\psi(\mathbf{x}, t) \mathbf{x}' = \gamma(\mathbf{x} - yt) \mathbf{t}' = \gamma(t - yt) \mathbf{x}'$  $dv^{\mu}/ds + \Gamma^{\mu}_{\nu\sigma}v^{\nu}v^{\sigma} = 0 \ R^{\mu}_{\nu\sigma\sigma} = \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma}\Gamma^{\mu}_{\alpha\rho} - \Gamma^{\alpha}_{\nu\sigma}\Gamma^{\mu}_{\alpha\rho} \ R_{\mu\nu} = R^{\mu}_{\mu\nu\rho} \ R = R^{\mu}_{\mu} \ G_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu}R = 0$  $2GM/R\int \psi^*\psi dx = 1 P(x,t) = |\psi(x,t)|^2 \psi(x,t) = |\psi(t)\rangle \langle x \rangle = \langle \psi|x|\psi \rangle \Delta x \Delta p \ge h/2 p_4 = -i\hbar\partial_4 E = i\hbar\partial/\partial t H = p^2/2m + V$  $+ V(x)\phi(x, t) = E\phi(x, t) x' = \gamma(x - yt) t' = \gamma(t - yx/c^2) \gamma = 1/(1 - y^2/c^2)^{1/2} x' = -t \sinh \xi + x \cosh \xi t' = t \cosh \xi - x \sinh \xi t t'$  $\epsilon_{11k} \partial_1 A_k \ F^{\mu\nu} = \partial^{\mu} A^{\nu} - \partial^{\nu} A^{\mu} \ \bar{F}^{\mu\nu} = 1/2 \epsilon^{\mu\nu\rho\sigma} F_{\rho\sigma} \ \partial_{\nu} F^{\mu\nu} = J^{\nu} \ \partial_{\nu} \bar{F}^{\mu\nu} = 0 \ \mathrm{d}s^2 = c^2 \mathrm{d}t^2 - \mathrm{d}s^2 - \mathrm{d}s^2 - \mathrm{d}s^2 = g_{\mu\nu} \mathrm{d}s^{\mu} \mathrm{d}s^{\nu} + J^{\mu\nu} \mathrm{d}s^{\mu} \mathrm{d}s^{\nu} + J^{\mu\nu} \mathrm{d}s^{\mu\nu} \mathrm{d}s^{\mu\nu} + J^{\mu\nu} \mathrm{d}s^{\mu\nu} \mathrm{d}s^{\mu\nu} + J^{\mu\nu} \mathrm{d}s^{\mu\nu} \mathrm{$  $a_{\mu}R = R_{\mu}^{R}G_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu}R = 0 \ G_{\mu\nu} = 8\pi GT_{\mu\nu} \ ds^{2} = (1 - 2GM/r)dt^{2} - dr^{2}/(1 - 2GM/r) - r^{2}d\theta^{2} - r^{2}\sin^{2}\theta d\phi^{2} \ \Delta\nu \approx 10^{-10} \ ds^{2} + 10^{-10} \ ds^{2} +$  $\Delta p \ge \hbar/2 \ p_1 = -\hbar \partial_1 \ E = i\hbar \partial/\partial t \ H = p^2/2m + V \ H|a\rangle = E|a\rangle \ U = e^{Ht/i\hbar} \ \mathbf{F} = m\mathbf{a} \ \mathbf{F} = GMm\mathbf{r}/r^3 \ \nabla \cdot \mathbf{E} = \rho/\epsilon \ \nabla \cdot \mathbf{B} = 0 \ \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$  $p^{\mu} = J^{\nu} \ \partial_{\nu} \beta^{\mu\nu} = 0 \ ds^2 = c^2 dt^2 - dx^2 - dy^2 - dz^2 \ ds^2 = g_{\mu\nu} dx^{\mu} dx^{\nu} \ g_{\mu\nu} (dx^{\mu}/dr) (dx^{\nu}/dr) = 1 \ \Gamma_{\mu\nu\sigma} = 1/2 (g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu}) + g_{\mu\sigma,\nu} - g_{\mu\sigma,\mu} - g_{\mu\sigma,$  $= E[a] U = e^{Ht/h} F = ma F = GMmr/e^3 \nabla \cdot E = \rho/\epsilon \nabla \cdot B = 0 \nabla \times E = -\partial B/\partial t \nabla \times B = \mu J + 1/e^2 \partial E/\partial t F = q(E + \mathbf{v} \times B) - h^2/2m\nabla^2 \psi$  $dx = \frac{1}{2} \left( \frac{1}{2} - \frac{1}{2} \right) \left( \frac{1}{2} - \frac{1}{2} - \frac{1}{2} \right) \left( \frac{1}{2} - \frac{1}{2} - \frac{1}$  $4y^2 - dz^2 - dz^2 - g_{\mu\nu}dz^\mu dz^\nu - g_{\mu\nu}dz^\mu dz^\nu - g_{\mu\nu}(dz^\mu/d\tau) = 1 \ \Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu}) \ dv^\mu/dz + \Gamma^\mu_{\mu\sigma}v^\nu v^\sigma = 0 \ R^\mu_{\mu\rho\sigma} = \Gamma^\mu_{\nu\sigma,\rho} - \Gamma^\mu_{\nu\rho,\sigma} + \Gamma^\alpha_{\nu\sigma} = \Gamma^\mu_{\nu\sigma,\nu} - \Gamma^\mu_{\nu\sigma,\nu} + \Gamma^\mu_{\nu\sigma,\nu} - \Gamma^\mu_{\nu\sigma,\nu} + \Gamma^\mu_{\nu\sigma} + \Gamma^\mu_{\sigma} +$  $2GM/r) = r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 \Delta v \approx v_c GM(1/r_c - 1/r_c) d^2 u/d\phi^2 + u - GM/A^2 - 3GMu^2 = 0 \delta = 2GM/R \left[\psi^* \psi dx = 1 P(x, t) = |\psi(x, t)|^2 \psi(x, t) = |\psi(x, t)|^2 d^2 u/d\phi^2 + u - GM/A^2 - 3GMu^2 = 0 \delta = 2GM/R \left[\psi^* \psi dx = 1 P(x, t) = |\psi(x, t)|^2 \psi(x, t) = |\psi(x, t)|^2 d^2 u/d\phi^2 + u - GM/A^2 - 3GMu^2 = 0 \delta = 2GM/R \left[\psi^* \psi dx = 1 P(x, t) = |\psi(x, t)|^2 \psi(x, t) = |\psi(x, t)|^2 d^2 u/d\phi^2 + u - GM/A^2 - 3GMu^2 = 0 \delta = 2GM/R \left[\psi^* \psi dx = 1 P(x, t) = |\psi(x, t)|^2 \psi(x, t) = |\psi(x, t)|^2 d^2 u/d\phi^2 + u - GM/A^2 - 3GMu^2 = 0 \delta = 2GM/R \left[\psi^* \psi dx = 1 P(x, t) = |\psi(x, t)|^2 \psi(x, t) = |\psi(x, t)|^2 d^2 u/d\phi^2 + u - GM/A^2 - 3GMu^2 = 0 \delta = 2GM/R \left[\psi^* \psi dx = 1 P(x, t) = |\psi(x, t)|^2 \psi(x, t) = |\psi(x, t)|^2 \psi(x, t) = |\psi(x, t)|^2 d^2 u/d\phi^2 + u - GM/A^2 - 3GMu^2 = 0 \delta = 2GM/R \left[\psi^* \psi dx = 1 P(x, t) = |\psi(x, t)|^2 \psi(x, t)$  $\nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t \nabla \times \mathbf{B} = \rho \mathbf{J} + 1/c^2 \partial \mathbf{E}/\partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2/2m \nabla^2 \psi(\mathbf{x}, t) + V(\mathbf{x})\psi(\mathbf{x}, t) = E\psi(\mathbf{x}, t) \mathbf{x}' = \gamma(x - vt) \mathbf{t}' = \gamma(t - vt) \mathbf{x}' + \frac{1}{2} (\mathbf{x} - vt) \mathbf{x}' + \frac{1}$  $(u-v)/(1-uv/c^2) \ p = \gamma mv \ E = \gamma mc^2 \ E^2 = p^2c^2 + m^2c^4 \ \partial_\mu J^\mu = 0 \ E_i = -1/c\partial A_i/\partial t - \partial_i\phi \ B_i = \epsilon_{ijk}\partial_j A_k \ F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu \ \tilde{F}^{\mu\nu} = 1/2\epsilon^{\mu} + 1/2\epsilon^{\mu} +$  $\Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu}) \ \mathrm{d}v^{\mu}/\mathrm{d}s + \Gamma^{\mu}_{\nu\sigma}v^{\nu}v^{\sigma} = 0 \ R^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\sigma} \Gamma^{\mu}_{\alpha\rho} - \Gamma^{\alpha}_{\alpha\rho} \Gamma^{\mu}_{\alpha\sigma} R_{\mu\nu} = R^{\mu}_{\mu\nu\rho} R = R^{\mu}_{\mu} \ G_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu} R = 0 \ R^{\mu}_{\mu\nu} = R^{\mu}_{\mu\nu} R_{\mu\nu} + R^{\mu}_{\mu\nu} R_{\mu\nu} R_{\mu\nu} = R^{\mu}_{\mu\nu} R_{\mu\nu} R_$  $e_{\lambda}1 \delta^2 u/d\phi^2 + u = GM/A^2 - 3GMu^2 = 0 \ \delta = 2GM/R \ \int \psi^* \psi dx = 1 \ P(x,t) = |\psi(x,t)|^2 \ \psi(x,t) = |\psi(t)\rangle \ \langle x \rangle = \langle \psi|x|\psi \rangle \ \Delta x \Delta p \ge \hbar/2 \ p_4 = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = p_4 \ A = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = p_4 \ A = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = p_4 \ A = -i\hbar\partial_4 \ A = -i\hbar\partial_4 \ E = i\hbar\partial/\partial t \ H = -i\hbar\partial_4 \ A = -i\hbar\partial_4$ 

#### MicroPython brings Python to resource-limited systems.

It allows rapid development of IoT applications.

Future development:

- continued development of ESP8266 port
- support for IoT: sensors, umqtt
- improved (micro)asyncio support
- optimise multithreading
- more features for the micro:bit, further ESA work

$$\begin{split} & S^{(2)} T^{(2)}_{(2)} = \delta_{1} T^{(2)}_{(2)} = 1 \quad d_{2}^{-1} = d_{1}^{-2} - d_{2}^{-2} - d_{2} - d_{2}^{-2} - d_{2} - d_{2}^{-2} - d_{2}^{-2} - d_{2} - d_$$

 $\sum_{k=1}^{n} (1 + i + i + i) (1 - i + i) (2 - i + i) (1 - i + i) (2 - i + i)$ 

 $\nabla H|_{0} = E|_{0} = E|_{0} = e^{Ht/i\hbar} \mathbf{F} = m\mathbf{a} \mathbf{F} = GMm\mathbf{r}/r^{3} \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$ 

 $a^{\prime} = (u - v)/(1 - uv/c^2) \ p = \gamma mv \ E = \gamma mc^2 \ E^2 = p^2 c^2 + m^2 c^4 \ \partial_{\mu} J^{\mu} = 0 \ E_i = -1/c \partial A_i$ 

 $= \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma} \Gamma^{\alpha}_{\mu\rho} - \Gamma^{\alpha}_{\nu\rho} \Gamma^{\alpha}_{\alpha\sigma} R_{\mu\nu} = R^{\mu}_{\mu\nu\rho} R = R^{\mu}_{\mu} G_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu}R = 0$   $(\psi(x, t))^{2} \psi(x, t) = |\psi(t)\rangle \langle x \rangle = \langle \psi | x | \psi \rangle \Delta x \Delta p \geq \hbar/2 p_{z} = -i\hbar\partial_{z} E = i\hbar\partial/\partial t H = p^{2}/2m + V$ 

#### micropython.org

forum.micropython.org
github.com/micropython



 $r/r^3 \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$  $= 1 \Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$  $1/c^2 \partial \mathbf{E} / \partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m \nabla^2 \psi$  $p^2 c^2 + m^2 c^4 \partial_\mu J^\mu = 0 E_i = -1/c \partial A_i$  $A_{\nu} F^{\mu\nu} = \partial^{\mu}A^{\nu} - \partial^{\nu}A^{\mu} \tilde{F}^{\mu\nu} = 1/2\epsilon^{\mu\nu}$  $P_{\mu\nu\rho}^{\rho} R = R_{\mu}^{\mu} G_{\mu\nu} = R_{\mu\nu} - 1/2g_{\mu\nu}R = 0$  $/2 p_i = -i\hbar \partial_i E = i\hbar \partial/\partial t H = p^2/2m + V$  $-t \sinh \xi + x \cosh \xi \ t' = t \cosh \xi - x \sinh \xi \ ta$  $^{2}dt^{2} - dx^{2} - dy^{2} - dz^{2} dz^{2} = g_{\mu\nu}dx^{\mu}dx^{\nu}$  $1 - 2GM/r) - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 \Delta \nu \approx$  $r/r^3 \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$  $\gamma T_0 u' = (u - v)/(1 - uv/c^2) p = \gamma mv$  $= 1 \Gamma_{\mu\nu\sigma} = 1/2(g_{\mu\nu,\sigma} + g_{\mu\sigma,\nu} - g_{\nu\sigma,\mu})$  $d^2 u/d\phi^2 + u - GM/A^2 - 3GMu^2 = 0 \delta =$  $1/c^2 \partial \mathbf{E} / \partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2 / 2m\nabla^2 \psi$  $p^2 c^2 + m^2 c^4 \partial_\mu J^\mu = 0 E_i = -1/c \partial A_i$ 

 $v^{\nu}v^{\sigma} = 0 R^{\mu}_{\nu\rho\sigma} = \Gamma^{\mu}_{\nu\sigma,\rho} - \Gamma^{\mu}_{\nu\rho,\sigma} + \Gamma^{\alpha}_{\nu\sigma}$ 

 $\sigma r/r^3 \nabla \cdot \mathbf{E} = \rho/\epsilon \nabla \cdot \mathbf{B} = 0 \nabla \times \mathbf{E} = -\partial \mathbf{B}/\partial t$ 

 $= \mu \mathbf{J} + 1/c^2 \partial \mathbf{E}/\partial t \mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B}) - \hbar^2/2m\nabla^2 \psi$ 

$$\begin{split} & d^{-1}(1 - g_{0}(1)t)^{-1} - t^{-1}dt^{2} - t^{-2} dt^{-1} dt^{2} dt^{-2} dt^{-2} & m_{1}^{-1} dt^{2} dt^{-2} dt^{-2} & m_{1}^{-1} dt^{2} dt^{-2} dt^{-2} & m_{1}^{-1} dt^{-2} dt^{-2} dt^{-2} dt^{-2} dt^{-2} \\ & = 0 \\ & d^{-1} dt^{-1} dt^{-1} dt^{-2} dt^{-2$$