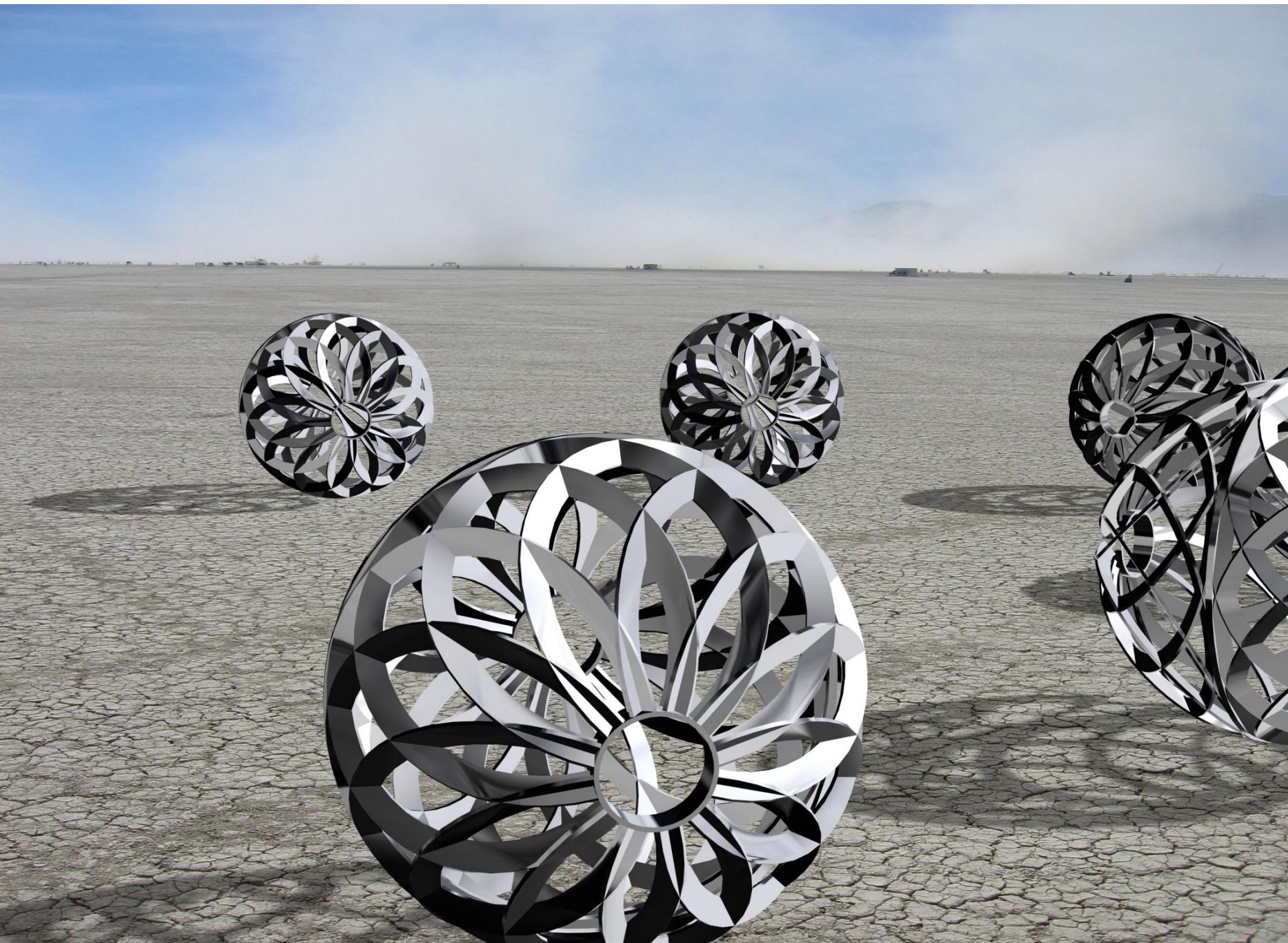


SWARM





What is SWARM?



' 'A motion and a spirit, that impels
All thinking things,
all objects of all thought
And rolls through all things.' '

W. Wordsworth

**A SWARM of rolling robot orbs
evolving complex dances of LIGHT and PATTERN.**

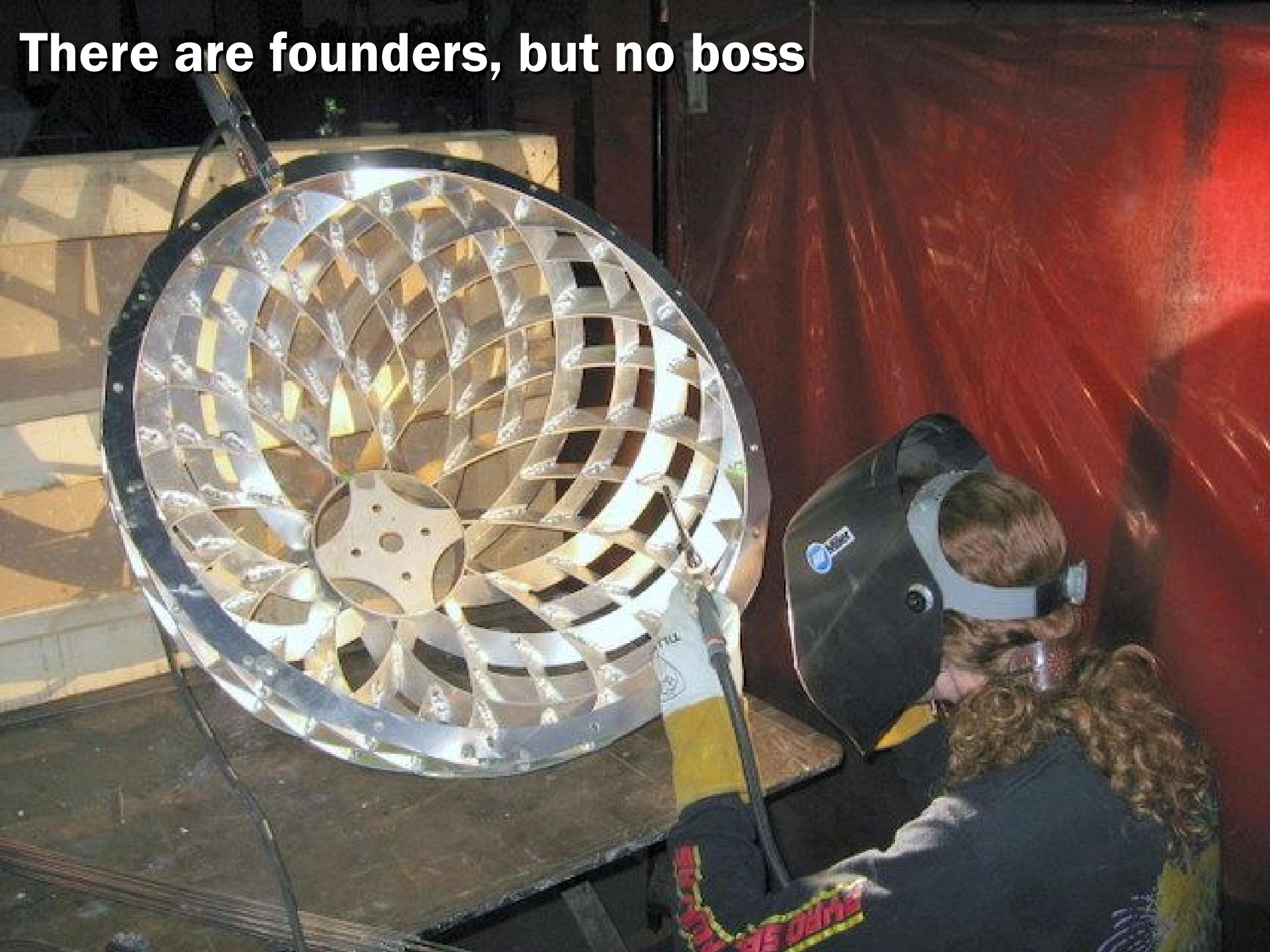
who are we?





**SWARM is an open-source collective of artists,
scientists, engineers and volunteers**

There are founders, but no boss



We are a
“do-ocracy”





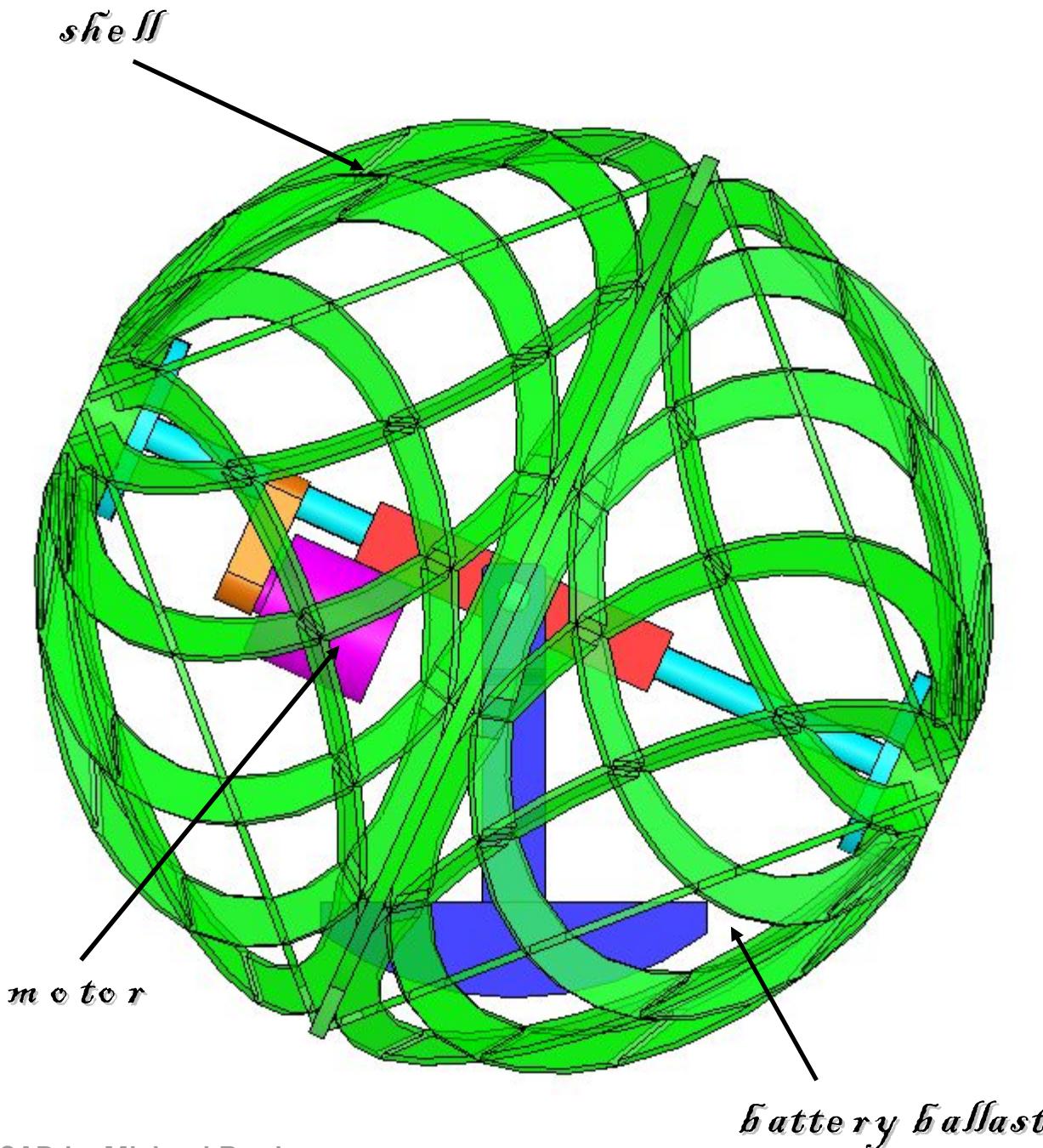
**We do this for everything
but money**

Funding:

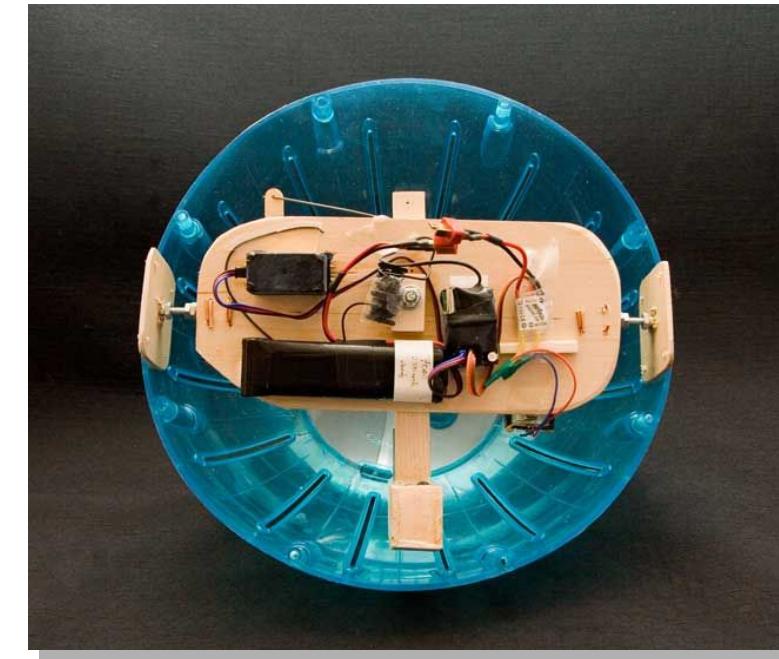
- Art Festivals (Burning Man, Coachella)
- Tech Festivals (Maker Faire, Techkriti)
- Corporate Functions (Google, etc.)
- Self-funding



how they work



CAD by Michael Prados



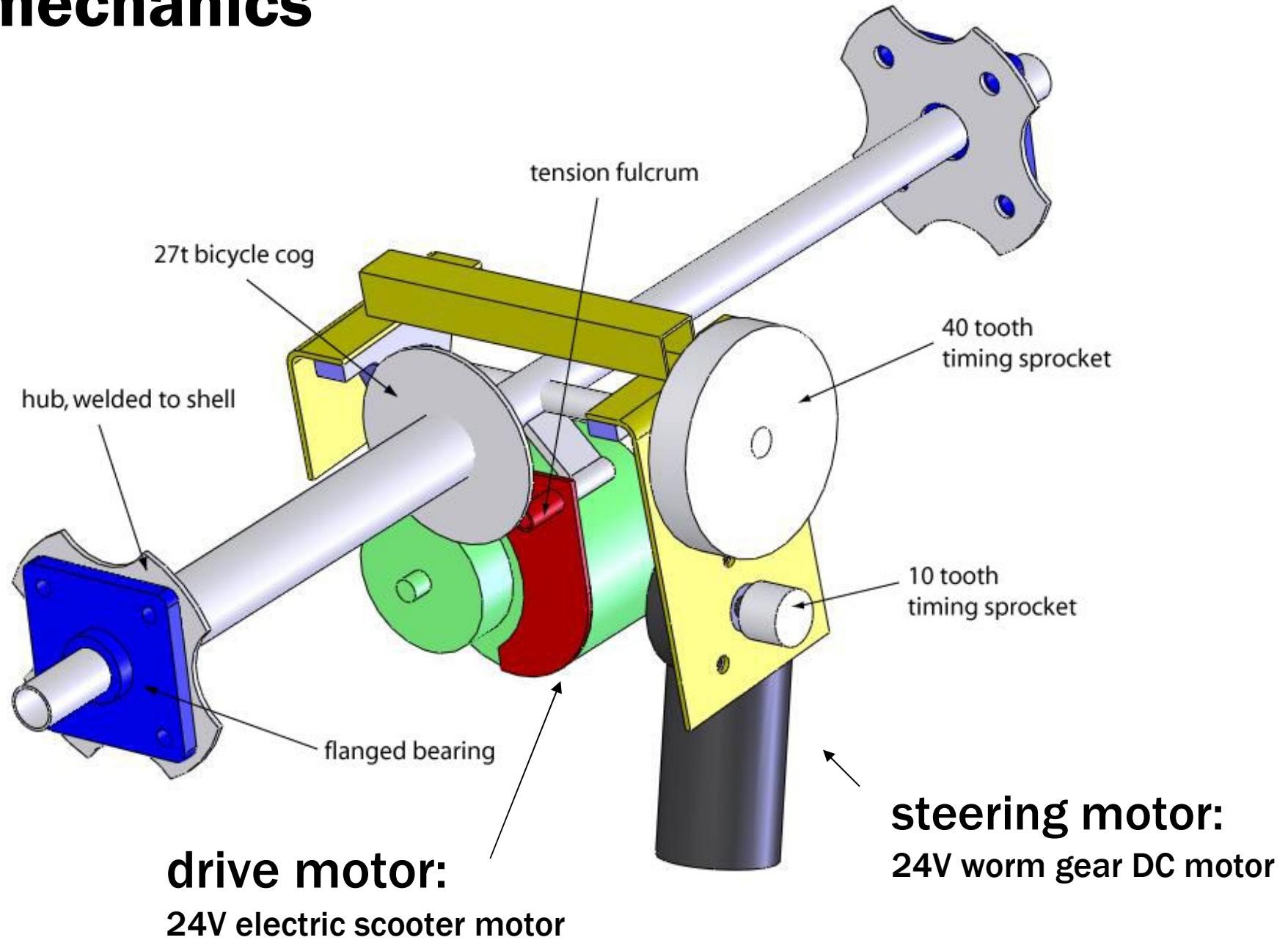
hamster ball prototype
by Pete Burnight

A heavy battery pack provides a reactive ballast.

A drive motor spins the shell against the ballast, causing the orb to roll

A steering motor tilts the ballast, allowing the orb to steer

drive mechanics



Swarm Kinematics

For no slip:

$$\rho = r \cos \phi$$

$$v = \dot{\theta} r \cos \phi = R \dot{\psi}$$

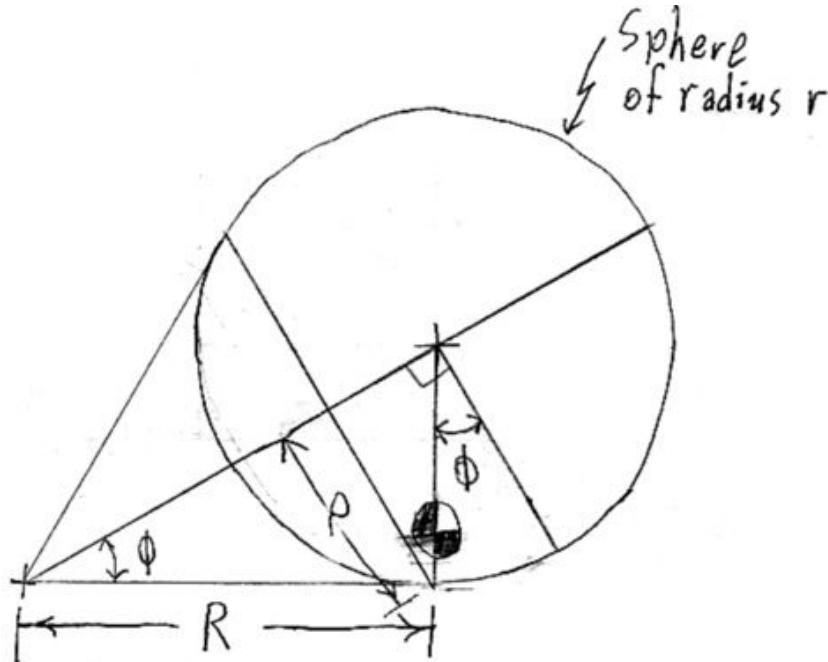
$$R = \frac{r}{\tan \phi} = r \cot \phi$$

$$\dot{\theta} r \cos \phi = \dot{\psi} r \frac{\cos \phi}{\sin \phi}$$

$$\dot{\psi} = \sin \phi \dot{\theta}$$

$$x = \cos \psi \quad v = \dot{\theta} r \cos \phi \cos \psi$$

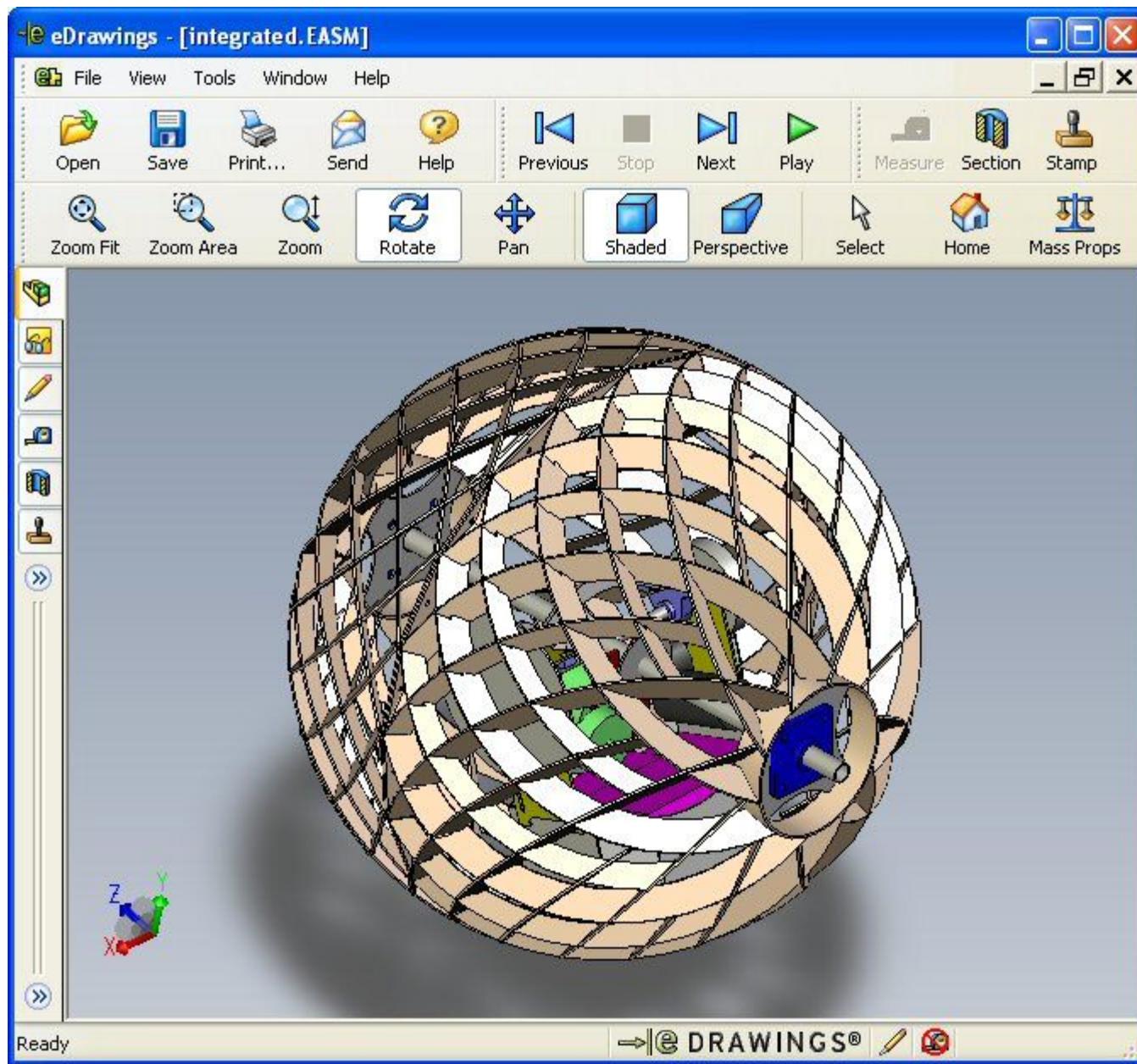
$$y = \dot{\theta} r \cos \phi \sin \psi$$



Rolling Cone Model

$$\psi_{des} = \text{atan} \left(\frac{y_{des} - y}{x_{des} - x} \right)$$

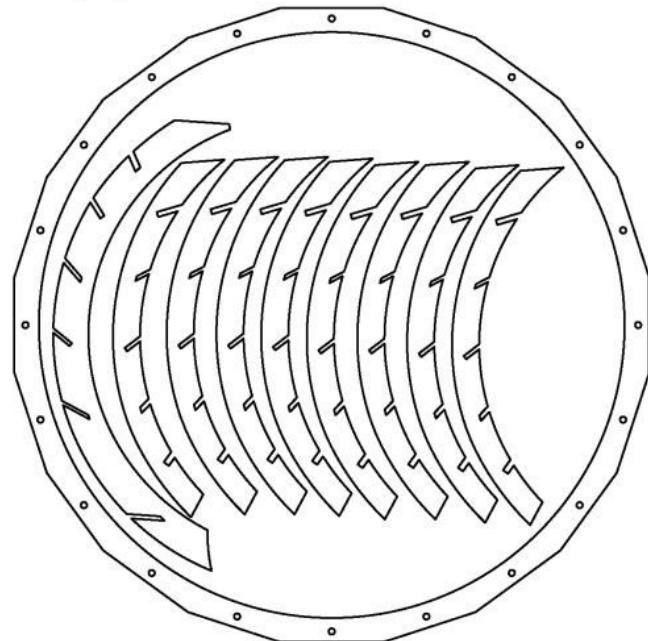
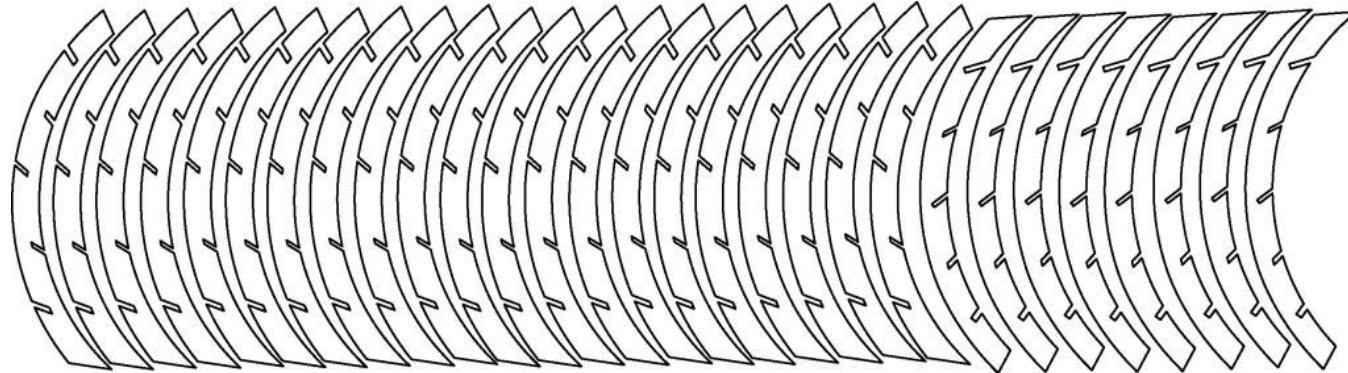
from design...



...an early prototype



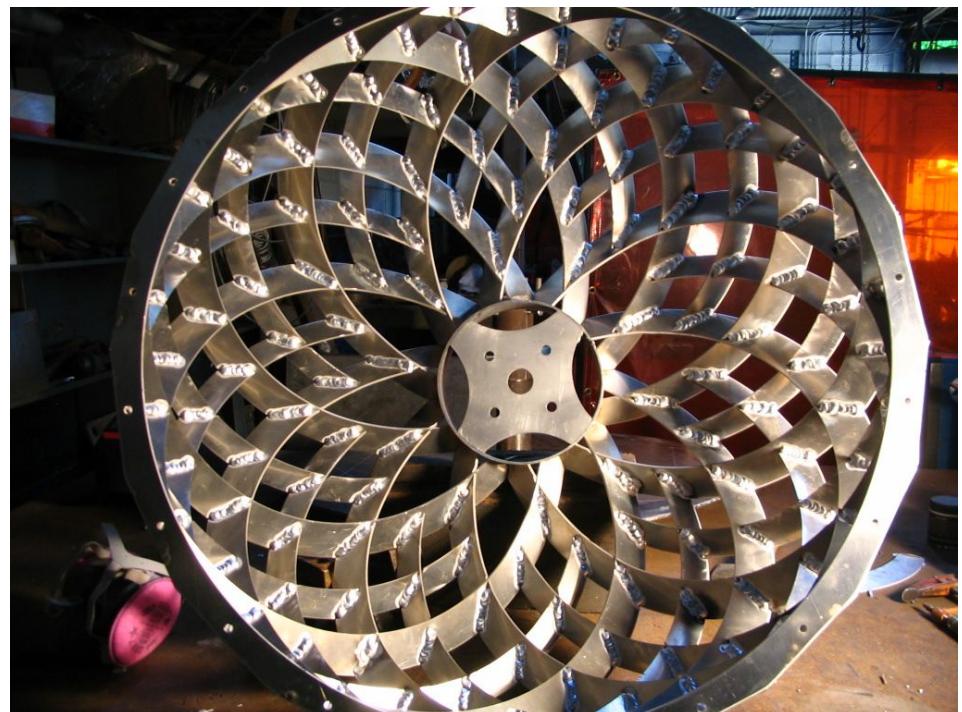
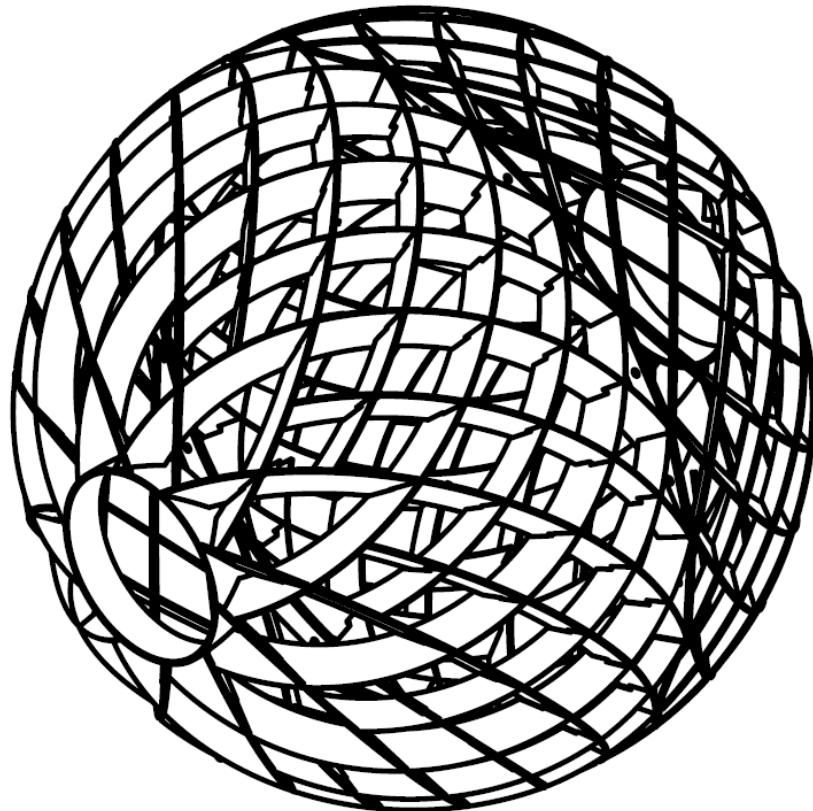
finally...



**waterjet cut 1/8 inch
aluminum sheet**



Shells:

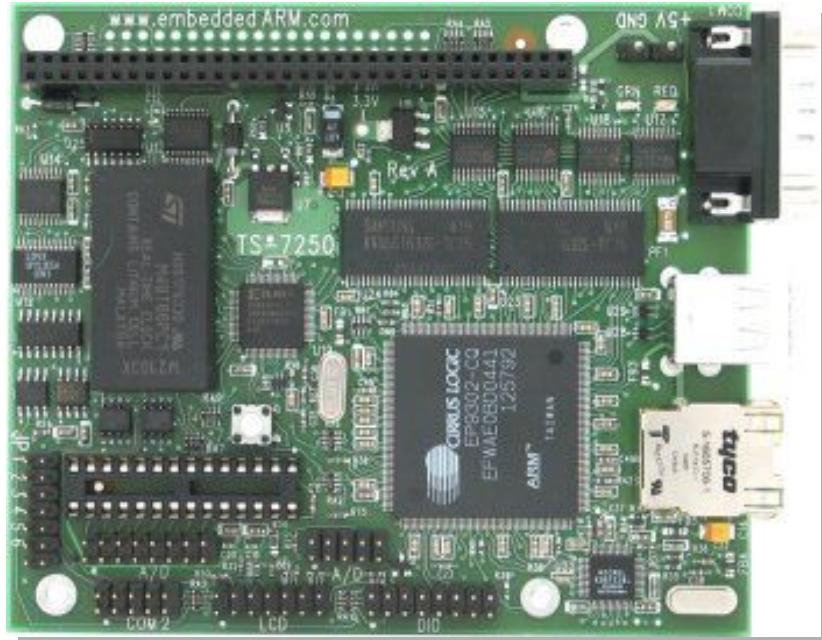


Chassis

Zigbee RF/Aggregator
LED illuminators
Sound module
CPU dome
Drive shaft and motor
Steering servo
Motor controllers
Battery pack

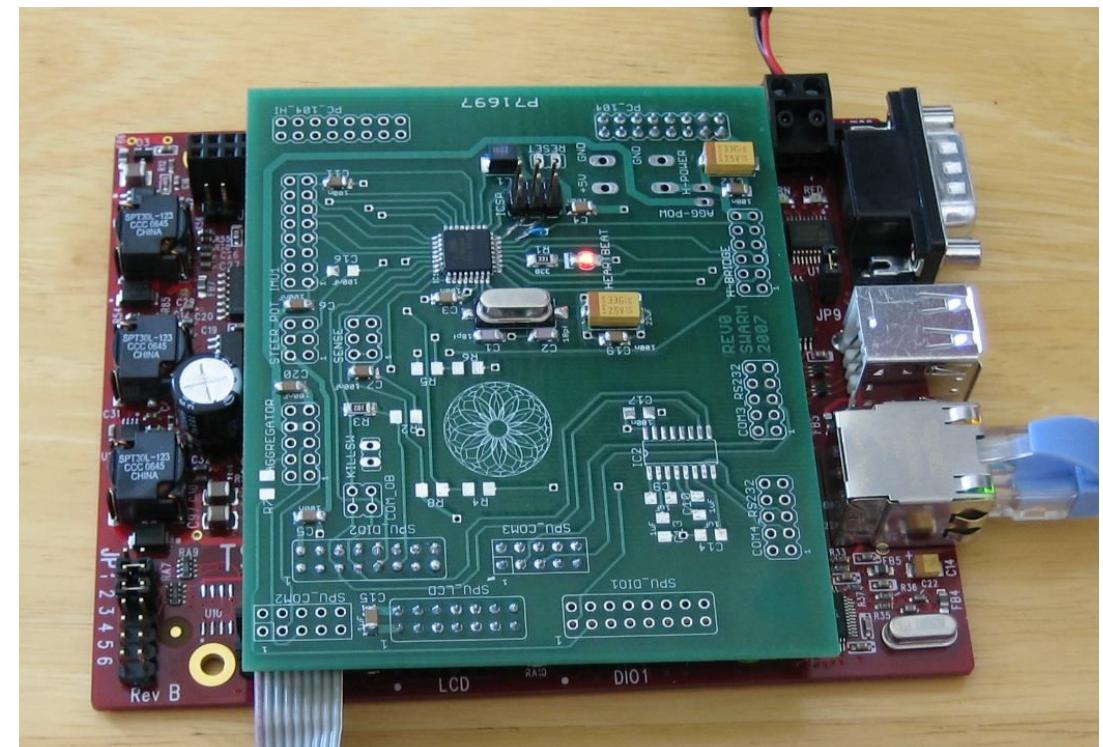


the brains of the operation



SPU – Swarm Processing Unit
200 MIPS Linux ARM processor
less than 1 watt power consumption
embeddedarm.com

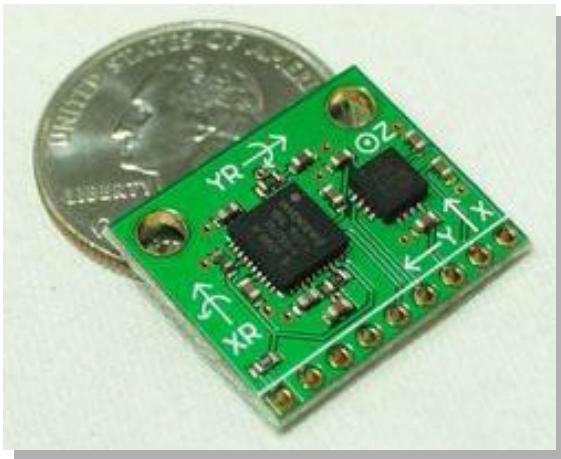
**Custom AVR daughterboard
for motor control, plus custom
H-bridge motor drivers**



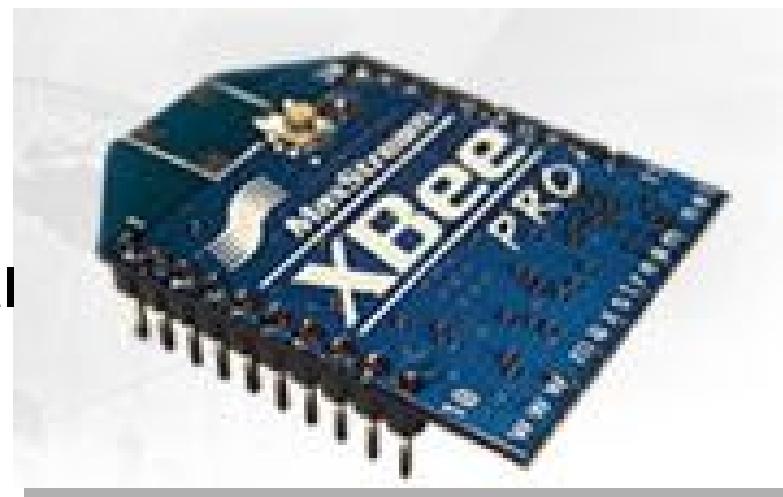
P.S. All our software is open source: www.orbswarm.com

sensors working overtime

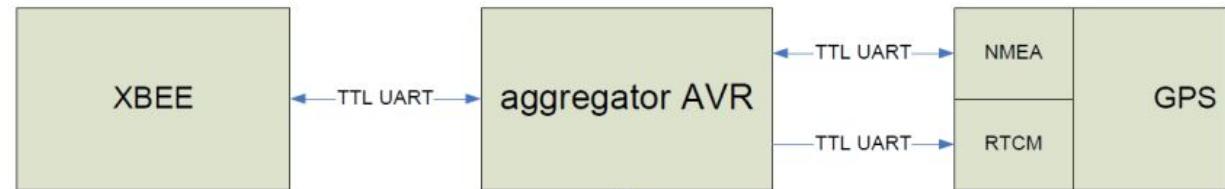
Global Positioning System (GPS) modules



Micro Electromechanical (MEMS)
accelerometers and yaw rate gyros
(sparkfun.com)



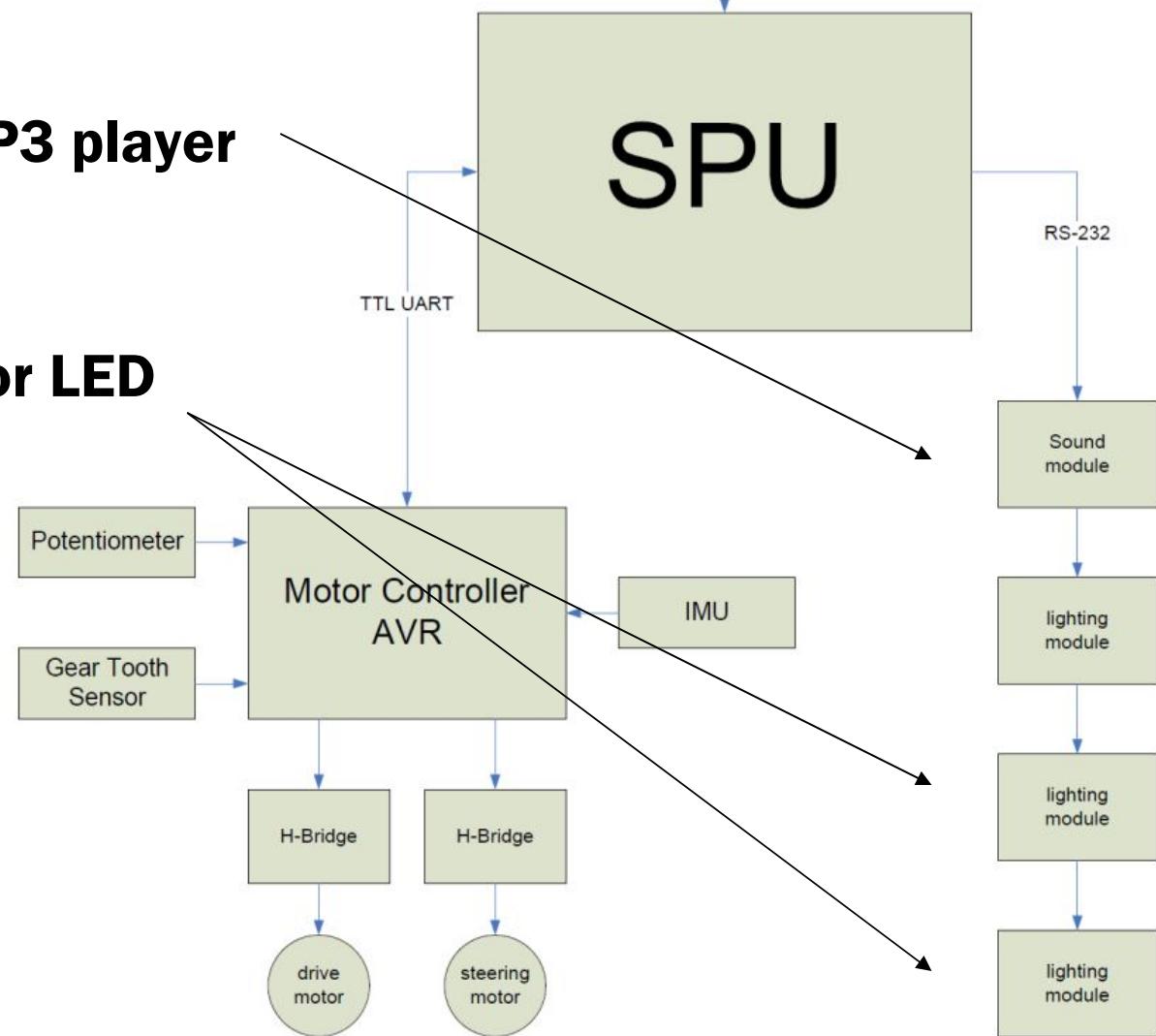
Zigbee radio for serial digital communication
xbee.com



artistic payload:

**serially-controlled MP3 player
and amplifier**

**fully controllable color LED
modules**



Extended Kalman Filter

- Necessary for systems with strong nonlinearity
 - Large angle motion- certainly greater than 180 degrees
 - Squares, cubes, exponentials

Predict

$$\hat{\mathbf{x}}_{k|k-1} = f(\hat{\mathbf{x}}_{k-1|k-1}, \mathbf{u}_k)$$

$$\mathbf{P}_{k|k-1} = \mathbf{F}_k \mathbf{P}_{k-1|k-1} \mathbf{F}_k^T + \mathbf{Q}_k$$

Update

$$\tilde{\mathbf{y}}_k = \mathbf{z}_k - h(\hat{\mathbf{x}}_{k|k-1})$$

$$\mathbf{S}_k = \mathbf{H}_k \mathbf{P}_{k|k-1} \mathbf{H}_k^T + \mathbf{R}_k$$

$$\mathbf{K}_k = \mathbf{P}_{k|k-1} \mathbf{H}_k \mathbf{S}_k^{-1}$$

$$\hat{\mathbf{x}}_{k|k} = \hat{\mathbf{x}}_{k|k-1} + \mathbf{K}_k \tilde{\mathbf{y}}_k$$

$$\mathbf{P}_{k|k} = (I - \mathbf{K}_k \mathbf{H}_k) \mathbf{P}_{k|k-1}$$

where the state transition and observation matrices are defined to be the following Jacobians

$$\mathbf{F}_k = \left. \frac{\partial f}{\partial \mathbf{x}} \right|_{\hat{\mathbf{x}}_{k-1|k-1}, \mathbf{u}_k}$$

$$\mathbf{H}_k = \left. \frac{\partial h}{\partial \mathbf{x}} \right|_{\hat{\mathbf{x}}_{k|k-1}}$$



SWARM Extended Kalman Filter

- 13 states

$$\dot{v}, v, \dot{\phi}, \phi, \theta, \psi, x, y, x_{ab}, y_{ab}, z_{ab}, x_{rb}, z_{rb}$$

- 10 sensors

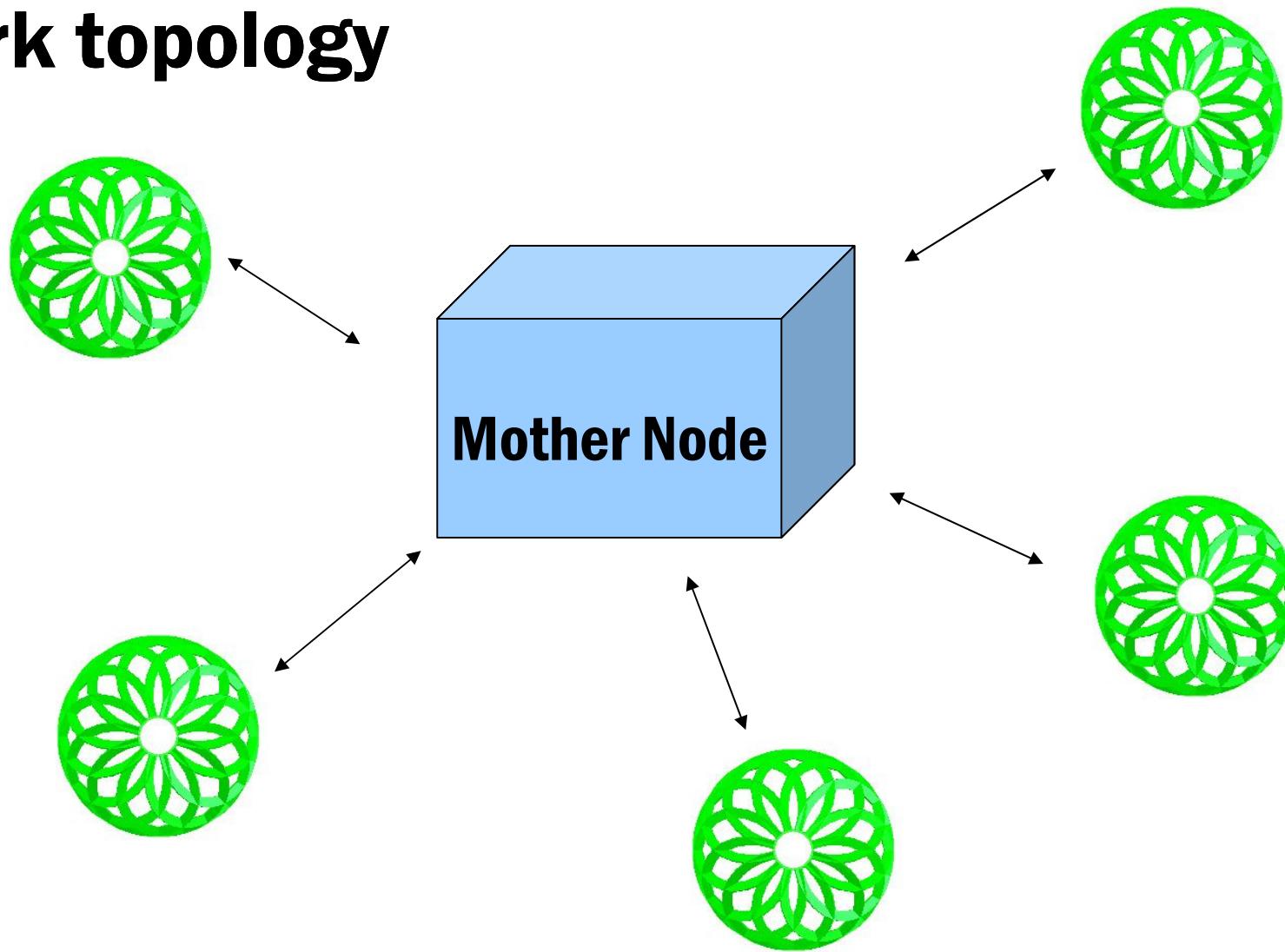
$$x_a, y_a, z_a, x_r, z_r, x_{gps}, y_{gps}, \psi_{gps}, v_{gps}, \omega$$

- Kinematic model – too big for slide.

- Work in progress! *info@orbswarm.com*



network topology



star network with round-robin polling

Mother Node is any PC (playa-proofed)

Orbs controlled with simple serial API

right... so how did they work?



they worked pretty great, actually



current capability: remote control



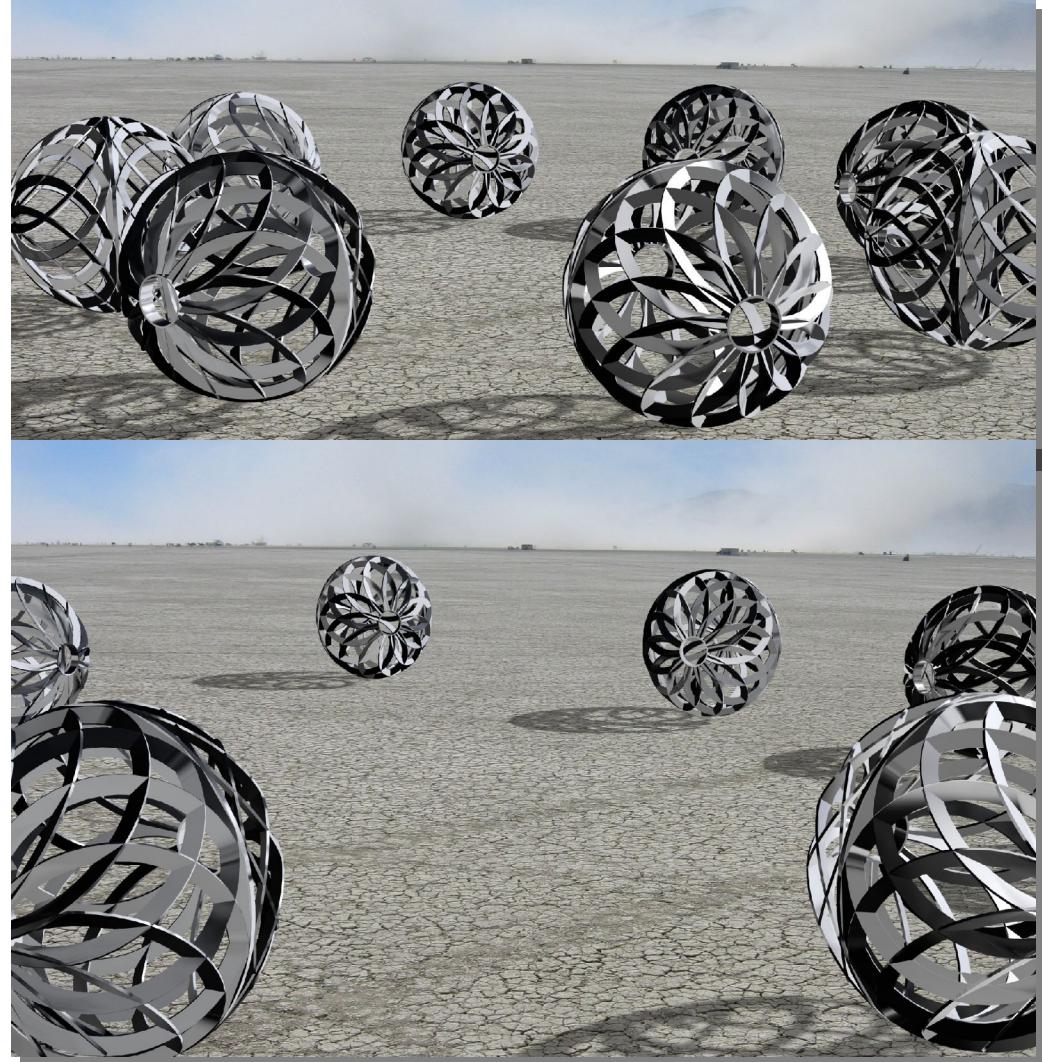
future vision: interactivity



The Magic Wand allows participants to control SWARM and direct formations like a sorcerer.

future vision: autonomy

**location-aware orbs
from GPS and inertial
sensor fusion,
permitting:**



- ◊ **interactive synchronized choreography**
- ◊ **autonomous and evolutionary behaviour**

An art form for the 21st century

thank you

www.orbswarm.com