HANDS ON DESIGN FOR HARDWARE

A Primer on Manufacturing and Ethnography of Use

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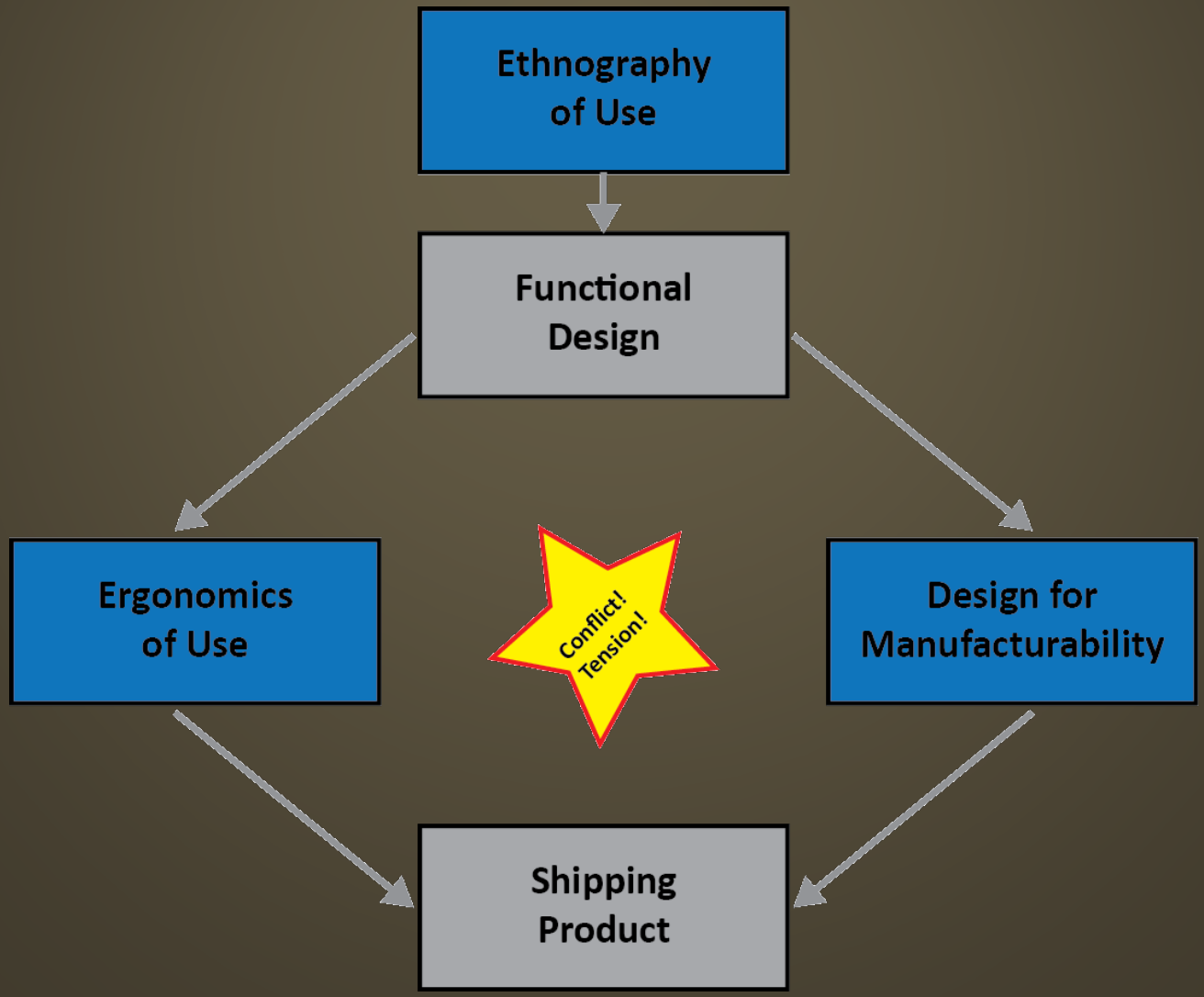
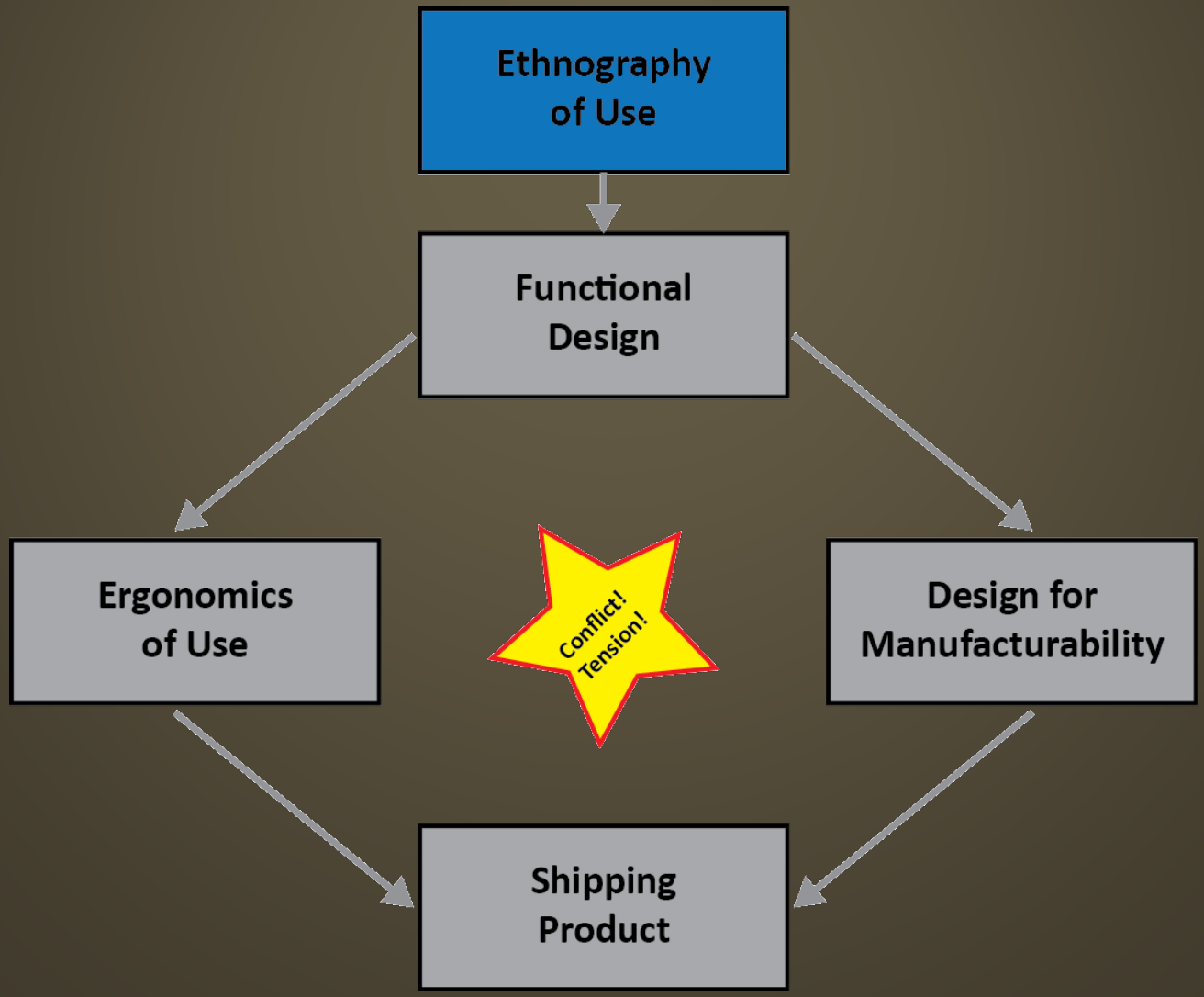
WHAT THIS TALK WILL COVER



PRODUCT DEVELOPMENT WORKFLOW – IN WORDS

- **ETHNOGRAPHY OF USE**
  - Choose your user. Learn their background and needs. Decide what kind of circuit you should design for MAXIMUM AWESOME.
- **FUNCTIONAL DESIGN**
  - Breadboard a circuit that functions. Then put it on a PCB. Solve all the technical challenges and do all the basic engineering work.
- **ERGONOMICS OF USE**
  - Re-design your board to make it robust in the hands of typical users. Make it easy to use. **GOAL**: push your use error down towards **0%.**
- **DESIGN FOR MANUFACTURABILITY**
  - Re-design the circuit to make it super simple, cheap, reliable and easy to manufacture. **GOAL**: get your yields up towards **100%.**
- **SHIPPING PRODUCT**
  - Release it into the wild. See how it performs. Maintain compatibility and make sure your critical components don't become obsolete. **REPEAT OVER LIFETIME CYCLE OF PRODUCT.**

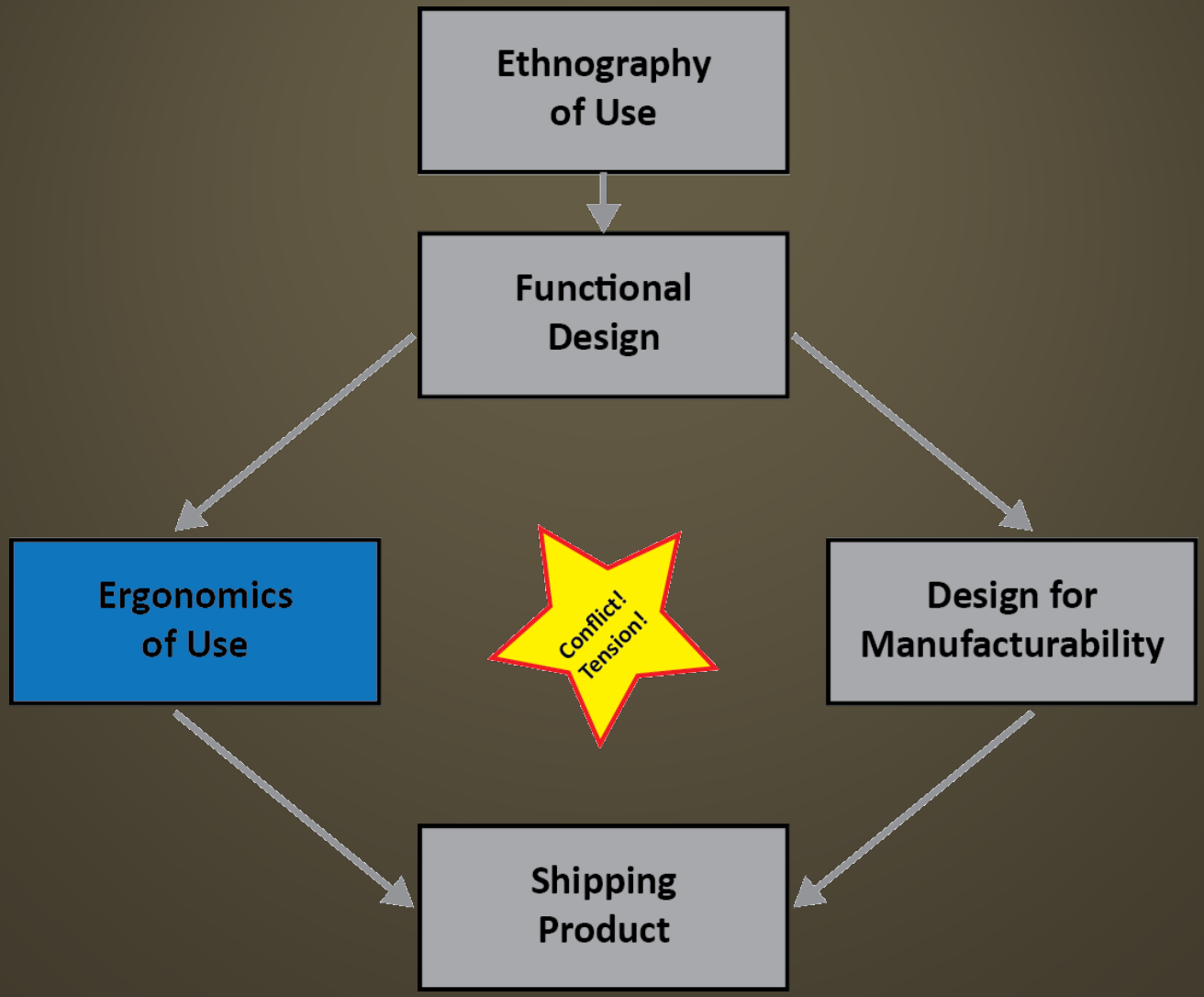
FIRST UP: ETHNOGRAPHY OF USE



ETHNOGRAPHY OF USE – THE BASIS FOR YOUR BUSINESS

- **IDENTIFY POSSIBLE USERS**
  (and market need)
  - Children, hobbyists, scientists, experts, audiophiles, roboticists, luddites, artists, robots, scientists, UNIX hackers, freegans...
- **CHOOSE YOUR USERS**
  (no really, pick one)
  - Every "ethnographic" user group has very different and specific needs. Choose one to focus on… or miss the region of convergence!
- **ETHNOGRAPHIC RESEARCH**
  (get to know your users)
  - Talk to real users to learn their requirements, background and experience. Avoid premature assumptions about what users know or want.
- **DESIGN AND PROTOTYPE**
  (you know how to do this)
  - Do what comes naturally. Just have your system requirements include what you learned from your "ethnographic research."
- **RUN REPEAT BETA TESTS**
  (with real users)
  - Give real users your prototype, or kit, or code and watch how they use it **WITHOUT EXTRA HELP**. See how they do. Fix your bugs. **Iterate.**

NEXT UP: ERGONOMICS OF USE



ERGONOMICS OF USE – VERY BRIEFLY

“The user is always RIGHT.”

and…

“There is no such thing as USER ERROR, only BAD DESIGN.”

and…

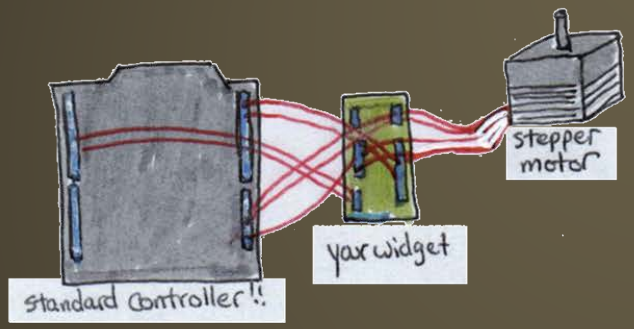
“RTFM is not an answer.”

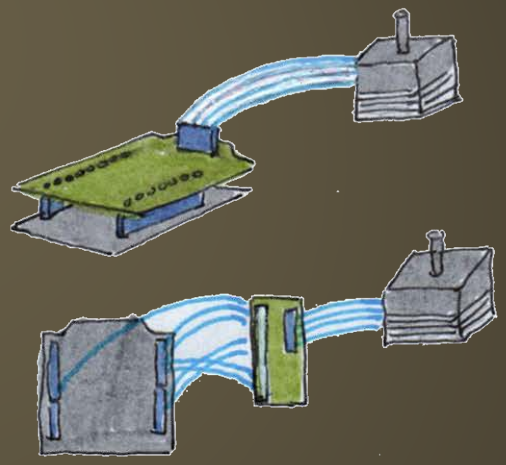
Ergonomics of use matters because you want your product to be useful and popular. When you have people using your product to ***make things***, having a successful product (and being very compatible with other successful products) is ***more effective than being “right.”***

Check out: Applying Human Factors and Usability Engineering to Optimize Medical Device Design
http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM259760.pdf

ERGONOMICS OF USE – KEY TIPS FOR ELECTRONICS

- **Floor-plan your interconnects & signal flow (try Fritzing!)**





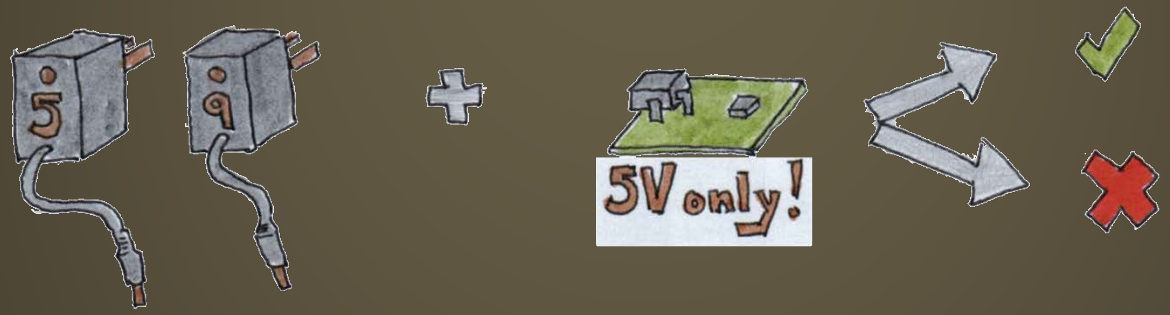
- **Use standard pin-outs and keyed/unidirectional connectors to minimize inverted connections**

- **PRO TIP: Avoid putting PWR and GND on symmetric pins**

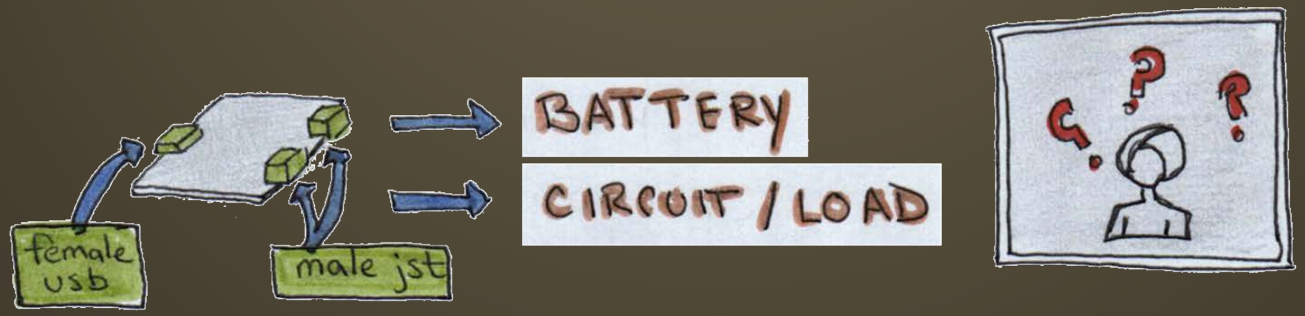
Check out: Fritzing! It's a really neat tool that will help you visualize physical wire crossover versus schematic complexity. Neat stuff!
http://fritzing.org/

ERGONOMICS OF USE – KEY TIPS FOR ELECTRONICS

- **Always use protection. Add input over-voltage protection and output over-current limits so your board can (temporarily) tolerate a range of use conditions without breaking.**



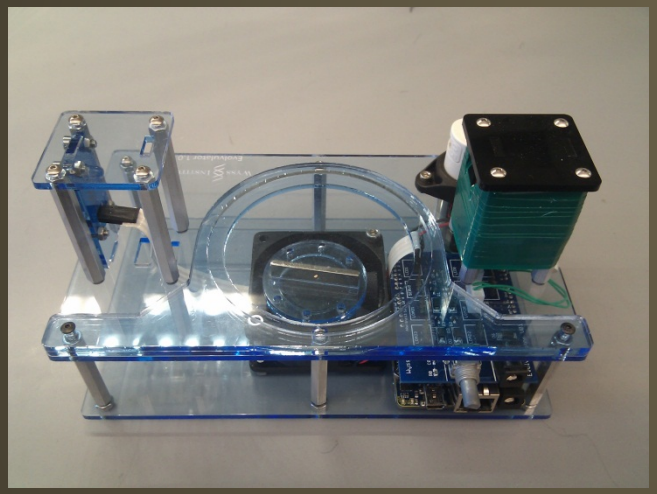
- **When possible, use function specific connectors.**

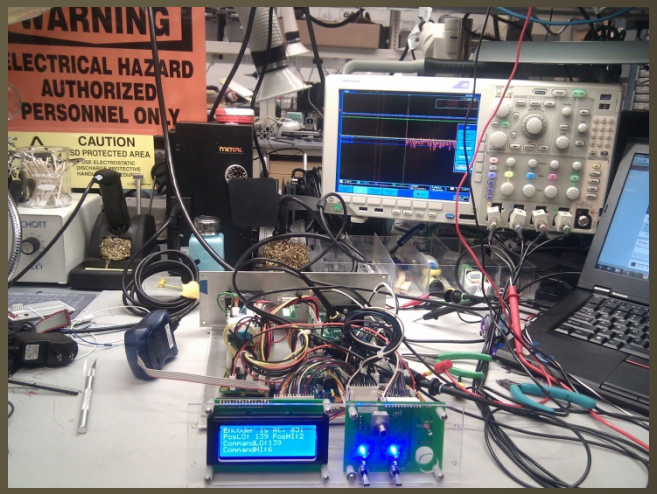


- **PRO TIP: You can't engineer around everything. The goal is to have your design survive typical use errors, not gross misuse.**

ERGONOMICS OF USE – MAKES GOOD BUSINESS SENSE

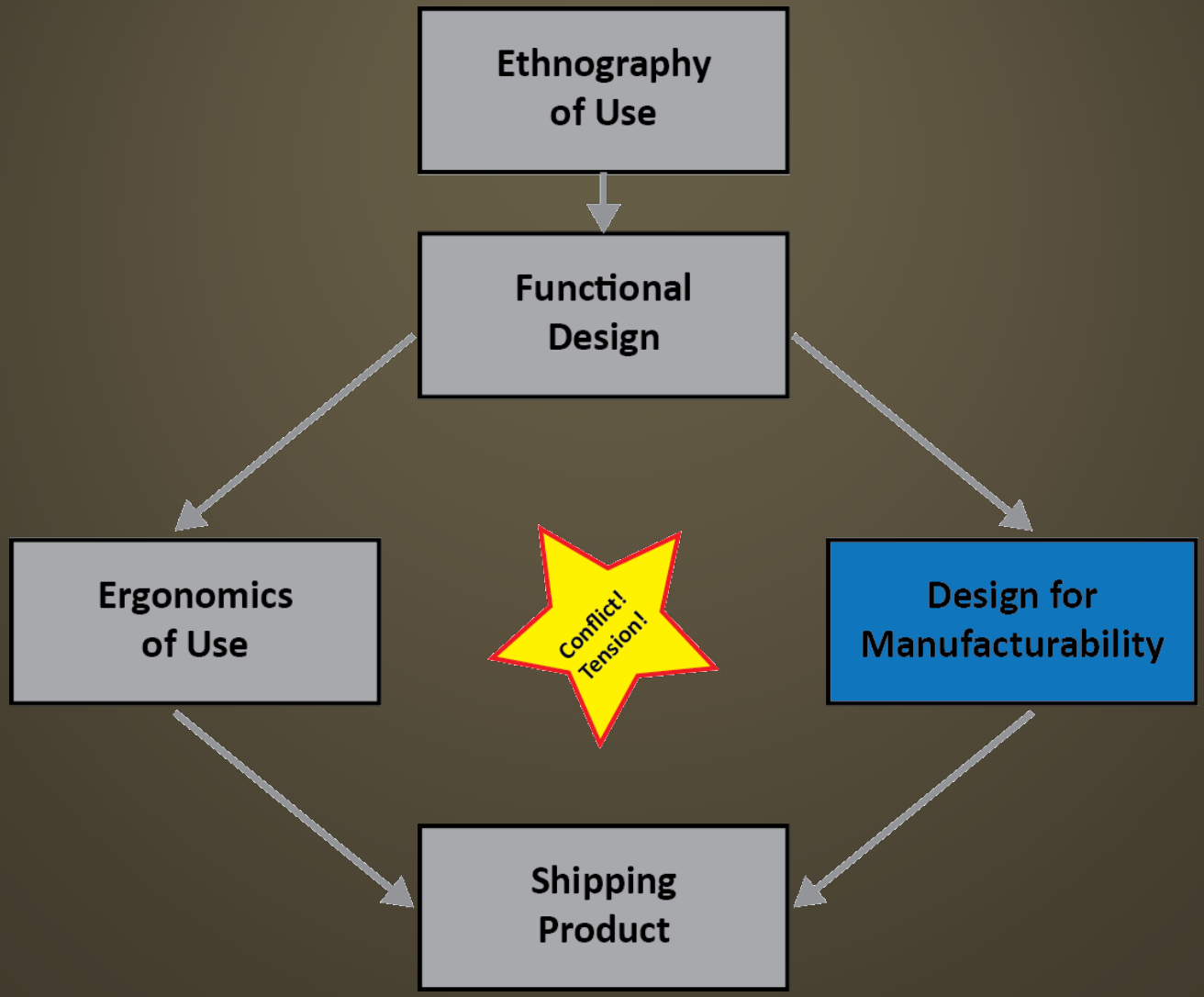
- **When you make a usable, extensible product… it goes places.**





- **Your product's "usability" goes beyond engineering the hardware:**
  - *Support software, IDEs, seamless device drivers*
  - *Portability (Windows, Mac, LINUX)*
  - *Library of typical circuit applications*
  - *Library of typical software/integration examples*
  - *Clear, readable documentation and up-to-date FAQs*
  - *Good customer support and troubleshooting help*
  - *Involving the community and incorporating user feedback*

NEXT UP: DFM


Ethnography of Use
Functional Design
Ergonomics of Use
Conflict! Tension!
Design for Manufacturability
Shipping Product

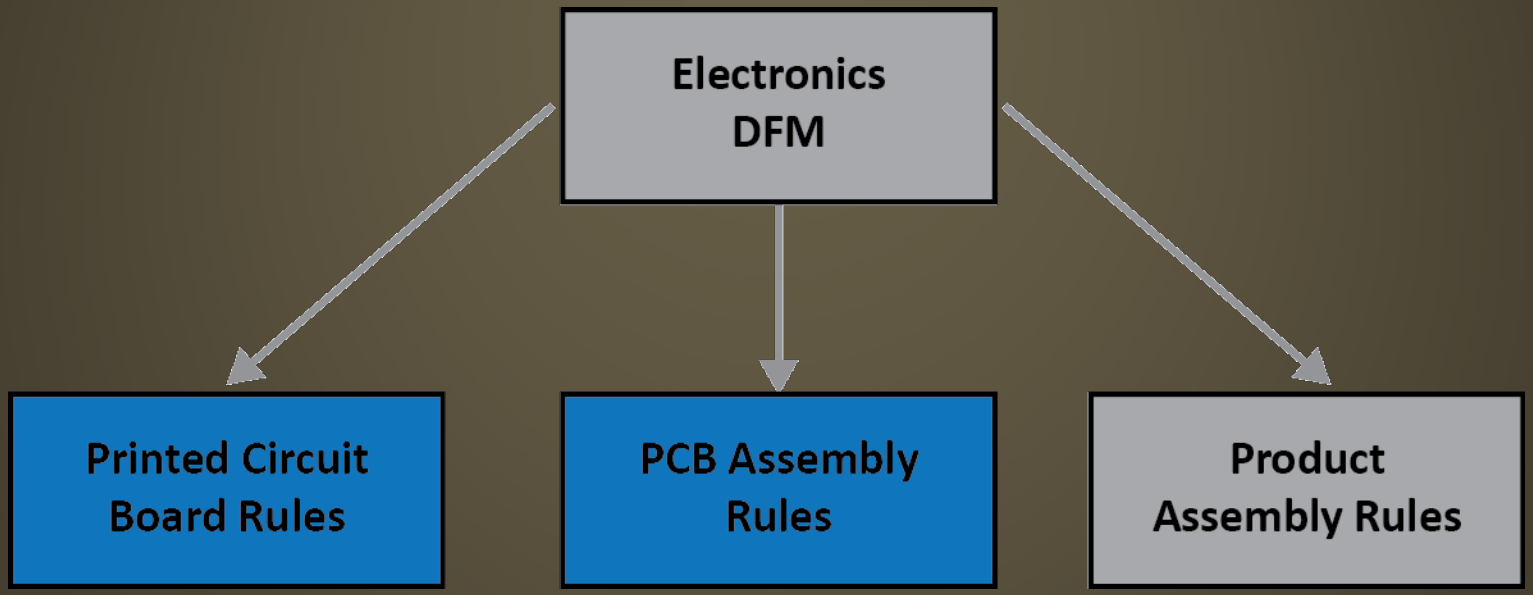
THE PHILOSOPHY OF DFM

- **Design for manufacturability is entirely about making sure that something is fast, cheap and easy to manufacture reliably.**

- **If you understand how something is made, the design rules for making it easily and reliably start to seem like common sense.**

- **PRO TIP: Your goal with DFM is to make your manufacturing vendor's life easier, since then you win. Ask about their process to learn their rules and learn from them! *Experts always like to talk shop*.**

DESIGN FOR MANUFACTURABILITY HAS MANY PARTS



- **It's going to be impossible to cover this in depth. Brace for checklists.**

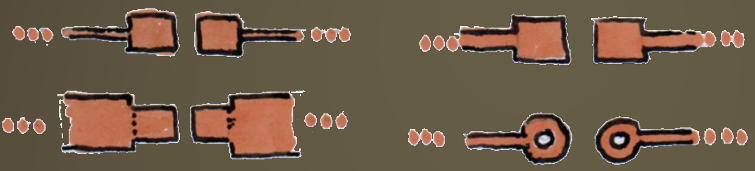
PRINTED CIRCUIT BOARD DFM

- **How most PCBs are made:**
  - ***Direct milling/routing of copper clad fiberglass***
  - ***Layer-by-layer lamination of lithographically etched copper + soldermask + drills + through-hole plating + surface finishes + silkscreen***
- **Read up on multiple PCB fabrication vendors' capabilities for the full range of possibilities in PCB manufacturing**
- **Increasing cost usually indicates that the design requires higher manufacturing precision to build (better tooling, more time)**
- **If the service is for sale… then it's manufacturable**
- **PRO TIP: Always use the vendor's DFM design checker**

I personally working with Advanced Circuits, but more importantly, I love their documentation. Check out:.
http://www.4pcb.com/engineering-cam-resources.html

PCB DFM – QUICK CHECKLIST FOR DESIGNERS

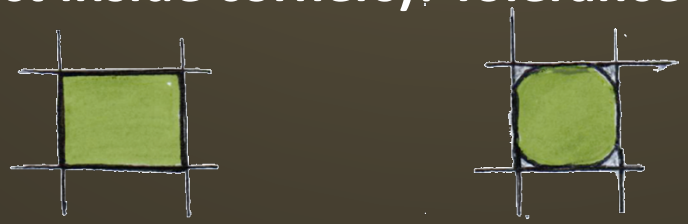
- **Where possible, use more copper (but not too much)!**



- **Use 45^{0} routing – avoid acute interior or exterior angles.**

- **Don’t put vias-in-pads or direct-connect part pads to copper pours.**

- **Don’t forget the slop! All routed shapes are drilled with round drill bits (no perfect inside corners)! Tolerance routed holes accordingly.**



PRINTED CIRCUIT BOARD ASSEMBLY DFM

“It’s all in the footprints.”

and…

“Footprints are assembly method dependent.”

TYPICAL ASSEMBLY METHODS

- **HUMAN ASSEMBLY**
  (hand soldering, single boards)
  - NOVICE
  - HOBBYIST
  - ADVANCED
  - CAREER TECHNICIAN

- **SEMI-AUTOMATED HUMAN-MACHINE HYBRID**
  (low to mid-volume production)
  - Pick & Place machine for SMD components
  - IR/thermal reflow soldering
  - Hand placement of odd components
  - Wave/Hand soldering (assembly-line fashion)
  - Human inspection/test

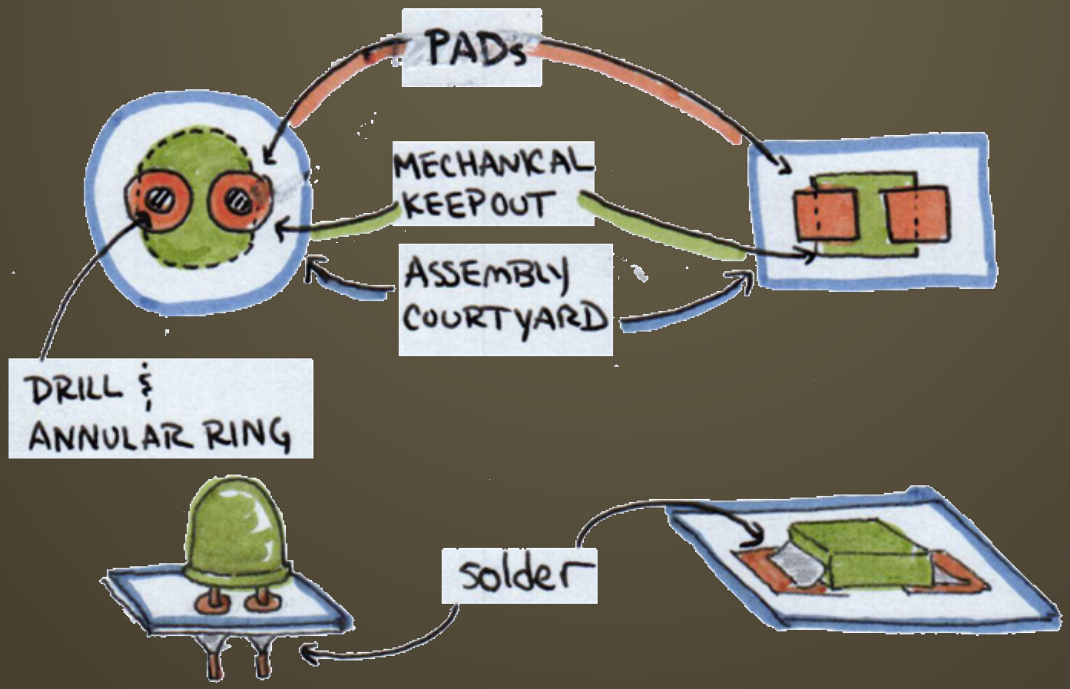
- **FULLY-AUTOMATED MACHINE ASSEMBLY**
  (high-volume production)
  - Massively parallel pick & place
  - Automated optical inspection
  - Automated Test
  - Humans perform sample verification and machine maintenance

Check out the Arduino Factory Tour from Adafruit: http://vimeo.com/35233146

ASSEMBLY DFM – UNDERSTANDING FOOTPRINTS

- **Part footprints are stored in your CAD program's Part Library**
- **SMD footprints are often called "pad landing patterns"**

TH = Through Hole **SMD = Surface Mount Device**



PARTS OF THE FOOTPRINT:

Pad; Drill (TH); Annular Ring (TH); Soldermask Relief; Solder Paste Area (SMD), Silkscreen Labels, ie - Reference Designator, Part Value, Pin 1

PCB design software vendor websites are a good source of information on part footprints.
Check out: http://www.pcbdesign.org/ and http://www.altium.com:443/community/libraries/aldc-standards/aldc-standards_home.cfm

COMPONENT FOOTPRINTS – WHERE TO FIND THEM

- **In many part datasheets, there's a back section with a lot of manufacturing data (Maxim, Analog, TI, NXP, TE-AMP, etc.)**

or…

IPC = Institute for Interconnecting and Packaging Electronic Circuits

aka…

"This one is *just* right."

The IPC is effectively an industry consortium of manufacturers and process engineers who have worked out land pattern geometries that are optimized for different soldering methods (namely wave and reflow soldering), for single- and double-sided assemblies, and for low, medium and high component placement densities. They've built this standard through experimentation, experience and a lot of manufacturing defect correlation. Don't knock it!

But. If you're designing for kits, experiment and learn what works for you!

Check out the IPC website: http://www.ipc.org/
Check out their reference list of IPC footprint calculators: http://www.ipc.org/ContentPage.aspx?pageid=PCB-Tools-and-Calculators

ASSEMBLY DFM – CHOOSING THE RIGHT FOOTPRINT

“Use what works for you.”

If you’re expecting someone (especially a novice with inexpensive equipment) to be assembling a project kit by hand, you’ll want to use larger components and make the pad sizes and courtyards more generous. If you need to go straight to high-density board design (teeny tiny chip-scale components, closely packed) – go straight to designing for a pick-and-place assembly process.

- **PRO TIP: Check out existing part libraries for your CAD tools.**
- **PRO TIP: Always trust but verify.**

When it comes to component libraries, always trust but verify. Existing 3rd party libraries for EAGLE are:
http://www.ladyada.net/library/pcb/eaglelibrary.html
http://www.microbuilder.eu/Projects/EagleFootprintLibrary.aspx
https://github.com/sparkfun/SparkFun-Eagle-Library

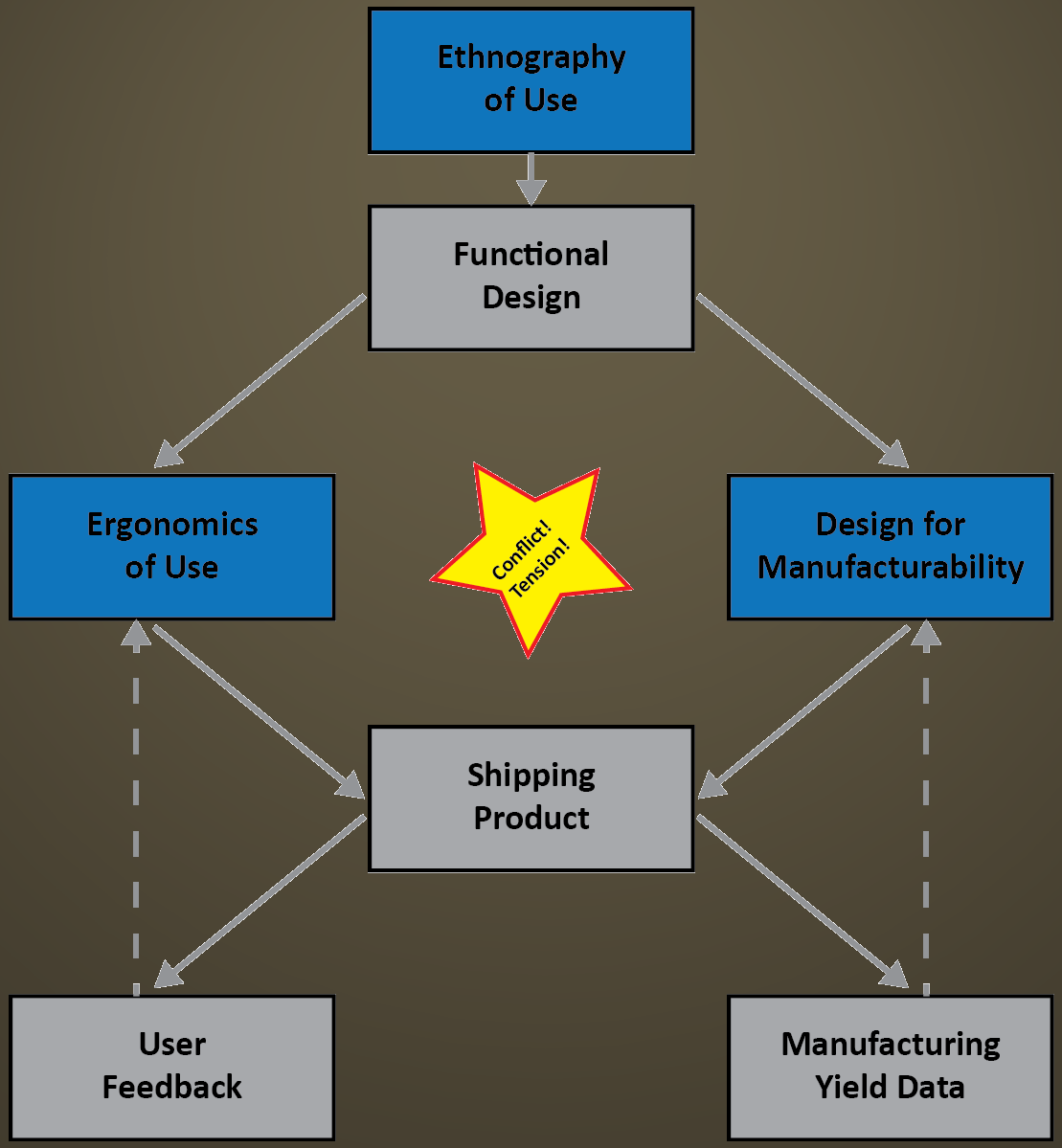
DFM TIPS FOR HUMAN ASSEMBLY

- Minimize the number of different part values (ie, 1K, 1K1…)
- Match the component type (TH vs SMD) and overall size to the human assembler's experience level and tool quality.
- Grow courtyards to match the assembler's experience/tools.
- Extend pads out (not in!) for easier re-work.
- Include clear visual registration features with silkscreen.
- Orient like parts in like directions (for easier rework).
- Try to keep all the components on the top side.

DFM TIPS FOR MACHINE ASSEMBLY

- Select component footprints compatible with the assembly house's capability – ALWAYS CONFIRM ASSEMBLY CAPABILITIES WITH THE VENDOR – breaking the rules is expensive.
- Keep all SMD parts on the top side for pick & place + reflow
- Keep all TH parts on the top side for wave soldering, but bottom-side is okay if hand-soldering
- Have clear silkscreen indicators for all hand-placed parts
- Have clear fiducial markers on each board and on the panels for pick & place registration and Automatic Optical Inspection
- Orient like parts in like directions (it's faster!)
- Give the assembly house a really detailed Bill Of Materials

WRAP: A MORE COMPLETE VIEW



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GOT QUESTIONS? GOT COMMENTS?

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