Making Computers Wearable

Applying the principles of functional clothing design to body-based electronic technology

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Forms of Wearability

- Body-mounted
- Garment-integrated
- Body-intrusive

Situational Analysis

Situational analysis in determining wearability

- Understand the user
- Understand the environment
- Understand the activity

Applications

- Applications should be inspired by a need.
- Avoid “creating” a need.
- Accommodate all of the user’s peripheral needs in the design

Computers and Clothing: A Functional Perspective

- Looking at the functions of computers and clothing can help us to reconcile their forms and applications
- Each offers distinct functionality that can augment the performance of the other.

Major Functions of Importance

- Service
- Protection
- Expression

Whole > Sum of Parts

	Service	**Expression**	**Protection**
Computers	high	high	limited
Clothing	limited	high	high
Wearables	significant	significant	significant

Designing for the Body

Body Tolerance for Pressure

- Some areas of the skin surface are more sensitive to pressure than others are.
- In general, the fleshier part of the body will accept pressure more comfortably than areas where bones are unpadded, particularly if the items causing the pressure are rigid and not shaped to contour to the body surface.
- Exceptions to the premise that fleshy areas better tolerate loads:
  - Female breasts, male genitals
  - Areas where major blood and lymph vessels and nerves lie close to the surface

Weight Distribution and Sensitivity

A typical method of carrying bag and packs. This places the weight of the bag on an area found by the Army study to tolerate the least amount of pressure — from 5 to 8 pounds/sq. in. before discomfort.

Pressure of Menswear on the Neck in Relation to Visual Performance

- In pretests, an ophthalmologist found that when a subject secured a tie to normal tightness around the neck, pulsing of the retinal vein ceased completely.
- In a critical flicker fusion test (timed responses to blinking light), subjects scored significantly higher with an open neckline than they did when they wore buttoned shirts and tightened ties.
- Visual performance did not return to normal immediately after tight neckwear was removed.

Leonora Langan and Susan M. Watkins, Cornell University

Human Factors, 1987, 29(1), 67-71

Solid Researched Evidence:

Unbalanced Loads

When a heavy pack is carried on one shoulder, that shoulder lifts and the opposite hip juts out to balance the body. Over time, this skewed posture leads to various body malfunctions and primes the body for injury.

Improper Posture

- Pinched nerves/wear at joints
- Slow flow of nutrients to tissues
- Slow removal of wastes from body

- Fatigue
- Priming the body for injury

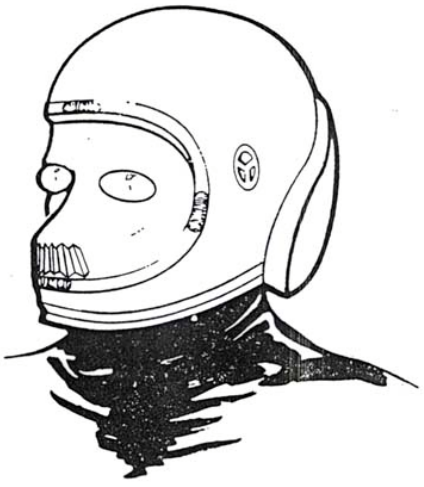
This respirator is unbalanced on the head because all of its components are placed in front of the nose and mouth.

In computer wearables, there are several kinds of inputs:
- information you speak or type in
- information sensed from your body
- information sensed from the environment

And a number of different kinds of outputs:
- information you hear
- information you see
- information you feel

Each of these could involve components placed on different areas of the body.

Distributed Weight



Elements of computer systems not properly integrated into clothing can:

- **Create a restriction** of movement; i.e., hobble body segments together and thus decrease body function
- **Increase the energy** needed to move in a garment, and give the wearer the perception that their movement is restricted

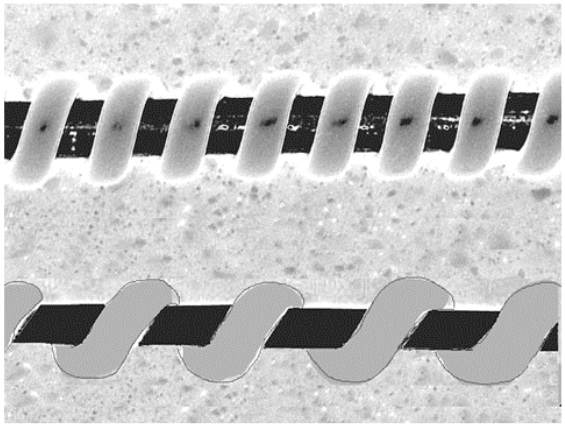
Factors Affecting Ease of Motion in a Garment

- Flexibility, bulk, and weight of fabrics: stretch; lack of stiffness; thinness; lightness
- Cut of garment: segment sizes and shapes
- Flexibility of design: absences of closures, design features and accessories, etc., that limit fabric stretch.
- Fit of garment: the ease and shaping of each part of a garment when worn by a specific individual
- Frictional drag of fabric: with the skin; between multiple layers of a garment

Stretch Fabrics

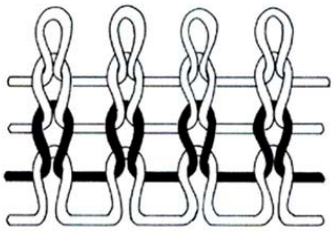
- Stretch fabrics have the advantages of:
  - maximum ease of mobility
  - contouring to a wide variety of body shapes
- Low modulus stretch fabrics have a disadvantage for wearable computers in that they may not provide sufficient stability to hold heavier items in place on the body

Stretch Fibers

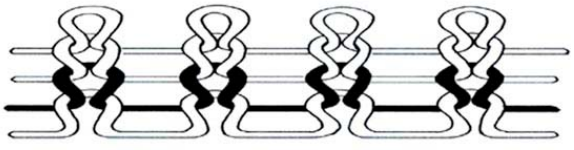


An elastomeric core wrapped in fiber. The fiber adds color, texture and strength to the yarn. As the elastic core extends, the fiber uncoils and allows the stretch to occur.

Knit Fabrics

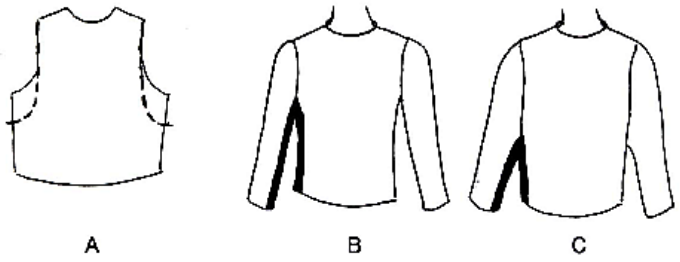


The yarns in knit structures are formed in loops.



The loops flatten and the fabric stretches as it is pulled.

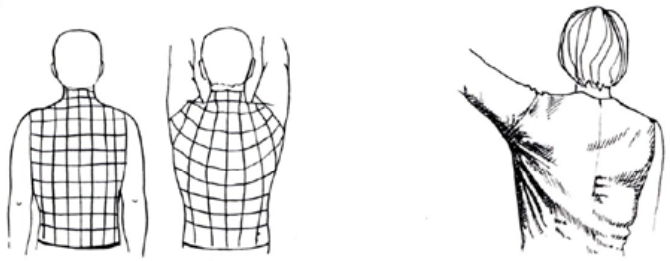
Garment Cut



A B C

Cutting a bigger armhole into a garment actually makes upward arm movement more difficult. Figure B shows the lenght of the underarm seam before the armhole is enlarged. Figure C shows the shorter distance the arm can be raised with the bigger armhole.

Changes in Body Dimensions

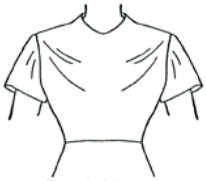


A B C

Figures A + B show how a square grid drawn on the body at ease is altered when the arms are raised over the head. Figure C shows how a raised arm strains a garment that fits at rest, creating tension at the armhole and down the entire garment side as it tries to accommodate the increased length of the body in motion.

Wrinkle Analysis

1. Diagonal wrinkles point to the source(s) of stress.



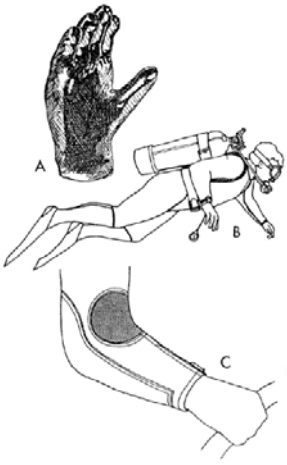
Diagonal wrinkles point to the shoulder indicating that there is not enough room there. (square shoulders)

2. Horizontal wrinkles on a garment part:
   a. If narrow and tight, mean the part is too tight.
   b. If full and loose, mean the part is too long.

Garment, seen from side, shows loose, horizontal wrinkles. Upper part of garment is too long below armhole in back.

3. Vertical wrinkles on a garment part:
   a. If narrow and tight, mean a part is too short.
   b. If full and loose, mean a segment is too wide.

Designing for the Working Position



Garments designed in the working position. A shows a rubber glove shaped in the natural position of the hand; B shows a wetsuit with the knees bent in the natural position the body takes underwater; C shows the sleeve of a motorcross jacket curved in the riding position.

Friction Between Layers

- Soldiers clothed in Arctic gear and exercising on a treadmill experienced 16% greater metabolic costs than those carrying the equivalent weight of the clothing in a belt worn around the waist.
- Researchers theorized that this increased cost was due to "**the frictional drag between layers"**, i.e., the frictional resistance as one layer of material slides over another during movement, and/or a hobbling effect of the clothing, i.e. interference with movement at the body's joints, produced by the bulk of the clothing.

Study by Teitlebaum and Goldman (1972) "Increased Energy Costs with Multiple Clothing Layers," Journal of Applied Physiology, 32 (6)743.

Supporting Hard Goods in Clothing

- Locate heavy weights close to the center of gravity of the body.
- Whenever possible, use the muscles of the legs and hips rather than those in the shoulders and upper torso to support weight carried on the body.

Supporting Hard Goods in Clothing, contd.

- Locate inflexible items away from the joints
- Analyze the movement patterns of the user and keep computer components out of areas where they will be moved by frequently repeated motions of the user.

Supporting Hard Goods in Clothing, contd.

- To add a heavy component to a garment:
  - allow the support device the maximum area contact with the body as possible, OR
  - reconfigure components so that they are in smaller units with weight distributed to several areas of the body.

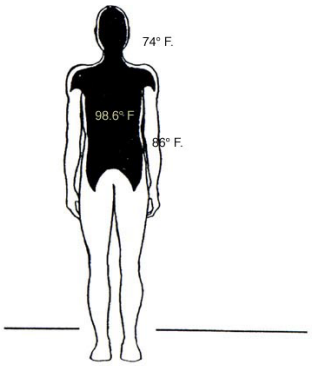
Supporting Hard Goods in Clothing, contd.

- To add a heavy component to a garment:
  - Avoid placing heavy items on body areas that are sensitive to pressure.
  - Reconfigure heavier computer components that cannot be converted to smaller, lighter units so that they are:
    - shaped to conform to the body surface
    - softer, more body-like in texture: flexible and/or cushioned against the skin.

Supporting Hard Goods in Clothing, contd.

- Pay attention to the location and structure of other items generally worn or carried by the user. In combination with computer components, they may cause mobility restrictions
- Use wrinkle analysis to determine where computer components may be adding stress.

Body Temperature



The body core includes the deep recesses of the torso and the head. The body works to keep the temperature of the core, where the vital organs are contained, within a narrow temperature range.

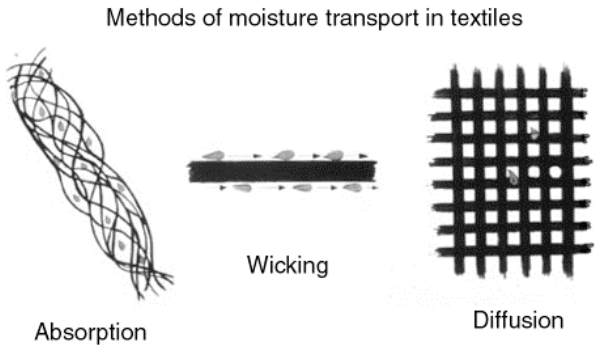
Some Thermal Dilemmas for Computer Wearables

- The human body constantly produces heat.
- Electronics often add heat to the body.
- Heat-producing components of computer wearables are generally located over the body core.
- Computer components are usually impermeable, so no air flow exists between them and the body, i.e. evaporation is impeded

Heat-Dissipating Garments Have:

- Thin, open-structured fabrics
- Minimal layering (single layer main garment; fewer pockets, collarbands, trims)
- Designs that provide minimal or loose coverage of the body
- Loose, open areas around the head, neck and upper torso (heat rises)
- Loose garment edges (armholes; cuffs; hems)

Moisture Transport



Cautions When Using Wicking Materials

- Wickers transport moisture - they keep it from evaporating on the skin surface whrer, in most cases, it could achieve the most effective cooling.
- Heat is a “pump” that moves moisture in wickers. If the environment is hotter than your body, moisture will be pushed back toward your skin surface.
- Wickers only work if there is an absorbent material or an air-filled environment beyond them into which the moisture can escape.

In areas covered by rigid, impermeable items:

- Use spacers
- Add a powered method of cooling (fan; liquid-cooled garment)
- Use wickers and absorbers as appropriate
- Use phase change materials

The Big Picture

Strengths

	Service	**Expression**	**Protection**
Computers	significant	significant	limited
Clothing	limited	significant	significant

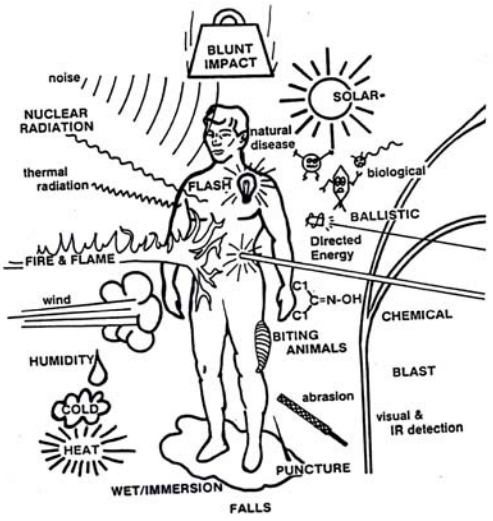
Service

- Computers: primarily service-oriented. Services involve data gathering, access, and processing.
- Clothing: limited service capabilities. Service limited to cargo storage and transport.

Protection

- Computers: Minimal physical protection systems, limited to personal alarms.
- Clothing: Proximity to body surface provides optimal location for physical protection.

Protection: Clothing



Expression

- Computers: Strongest expressive channel is communication. Dynamic communication (through language, images, sounds)
- Clothing: Expression is a significant function. Static communication through shape, color, image, or even written word.

Whole > Sum of Parts

	Service	Expression	Protection
Computers	high	high	limited
Clothing	limited	high	high
Wearables	significant	significant	significant

Wearables: Service

- Augmented clothing can store both physical objects and data
- Remember the pocket metaphor as an interface--the physical act of placing something in a pocket can be equated to “saving” data
- Horizon: clothing that can perform physical “work”--prosthetic muscles, for instance.

Wearables: Service

Orthowalk®, ILC Dover

Wearables: Expression

- Augment clothing with communication capabilities of electronic devices (phone, email, data transfer)
- Electronic augmentation of non-verbal expression: dynamic expression similar to that seen in the animal kingdom

Wearables: Protection

- Electronic surveillance of homeostasis state (alert to changes)
- Emergency communications (alert medics, police, etc)
- Electronically induced changes in immediate environment (temperature, sounds, etc)

Wearables: Protection

Image credit: Komposite

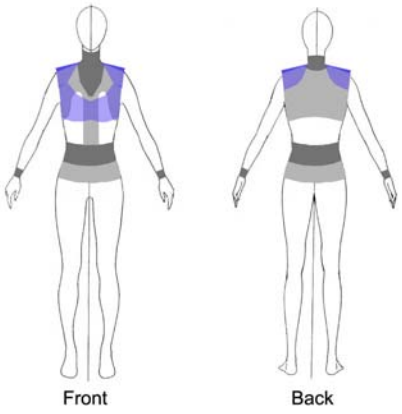
Reaching the "Horizon"

- Broader understanding of user needs (physical, situational, emotional, intellectual)
- Expanded notions of the potentials of clothing
- Higher level of integration between electronics and garments (moving beyond pockets)

Adapting Existing Garment Features for Electronic Functionality

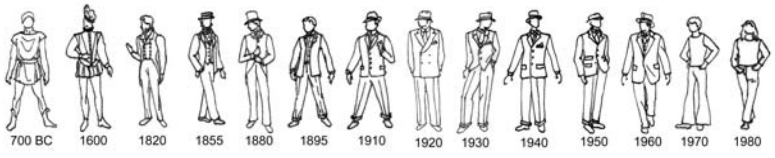
- Within the current structure and tradition of clothing there exist opportunities for easy integration of technologies
- Using these opportunities is a good way to incorporate technology into a garment without visibly changing the garment or requiring the user to conceptualize their clothing differently

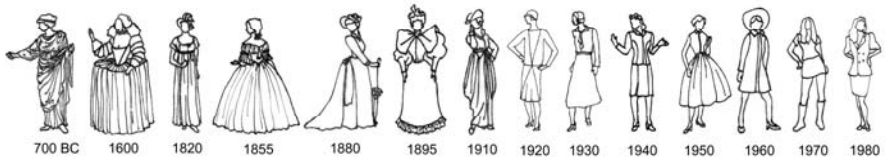
Use of Garment Spaces to House Electronics



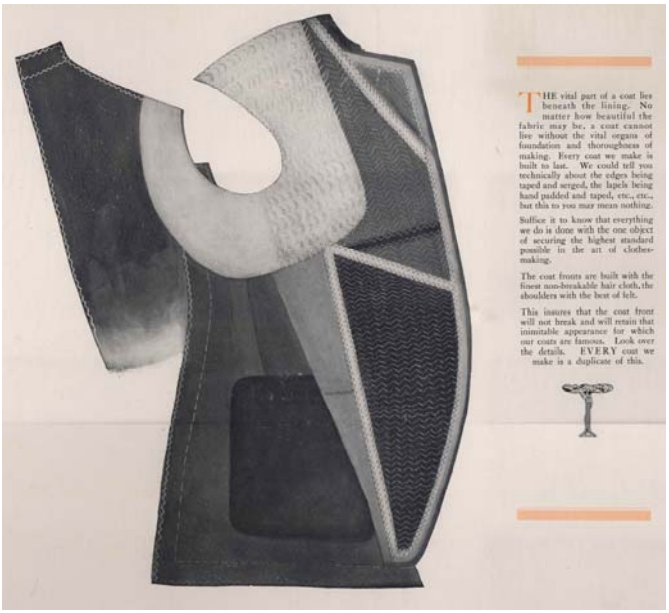
Garment areas that traditionally require padding (blue) or interfacing (gray)

Changes in Available Space Based on Fashionable Silhouette





Interior of a Suit Jacket



Adapting Garment Features for Electronic Functionality

- Fastenings: Hooks, zippers, snaps, buttons, Velcro®
- Other metal hardware

Supporting Electronics

- Addition of seams or wire conduits
- Padding for comfort and structure
- Minimizing outward appearance of electronics
- Supporting electronics close to the body

Integration of Hard Components

- Avoid flex areas
- Incorporate flexibility where possible
- Use padding and ergonomic shapes

Shapes

- Rounding sharp edges can reduce painful pressure points.
- Shapes should optimally be contoured to the body part that they will fit.
- Tapered shapes will reduce outward visibility of integrated technology

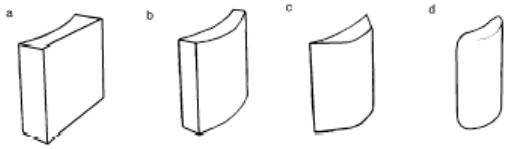
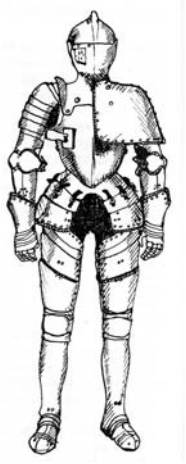


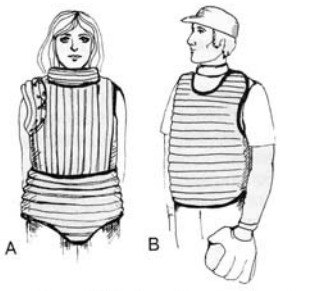
Image: Gemperle et al., "Design for Wearability", 1998

Modularity

- Modularity can improve flexibility of physical forms as well as flexibility of functions.
- Modularity can permit articulation in solid forms

Articulation





Segmented body padding. *A*, a woman's softball protector segmented vertically on top to conform to the female anatomy and horizontally below to accommodate the crouched position of the catcher behind the plate; *B*, a typical catcher's chest protector for men.

Flexibility

- Flexible PCBs
- Flexible displays
- Flexible conductors

Flexible Conductors

- Conductive fibers/yarns
- Conductive inks
- Embedded composite conductors

The Bigger Picture

"Railroad carriages are pulled at the enormous speed of fifteen miles per hour by "engines" which, in addition to endangering life and limb of passengers, roar and snort their way through the countryside, setting fire to crops, scaring the livestock, and frightening women and children. The Almighty certainly never intended that people should travel at such breakneck speed."

Martin Van Buren, 1829

"This 'telephone' has too many shortcomings to be seriously considered as a means of communication. The device is inherently of no value to us."

Western Union internal memo, 1876.

"Aerial flight is one of that class of problems with which men will never be able to cope.”

Simon Newcomb, 1903

"I think there is a world market for maybe five computers."

Thomas Watson Sr, chairman of IBM, 1943

"I have traveled the length and breadth of this country and talked with the best people, and I can assure you that data processing is a fad that won't last out the year."

Editor, Prentice Hall, 1957

Re-conceptualizing Wearable Computers for Mass-Market Acceptance

- Understanding the relationship between devices, individuals, and the larger context of society can help us to design applications that are useful and attractive to users.
- Examining the current structure of clothing and computers can help to forecast future advances, provide development goals, and clarify the issues involved in engineering change.

Re-conceptualizing Electronic Components for use with Apparel

- Integration at the textile level
- Integration at the fiber level
- Distributing electronics throughout a garment system
- Applications and interfaces

"Natural" Interfaces

- Use automatic responses to guide automated functions and reduce cognitive load:
  - Physical responses: heart rate, breathing (frequency and quality), GSR, EMG, sweating (amount and chemical composition), temperature, body movement, eye-tracking, blink rate, salivation, EEG, vocal pitch/verbal cues
  - Environmental cues: using context awareness to provide appropriate functions
- Use natural movements to guide interfaces

Re-conceptualizing Apparel

- Gradual modification of clothing concepts to support long-term electronics
- Ultimately new technology will change the way clothing is perceived, worn, used, and disposed of

Re-conceptualizing Apparel

- Gradual changes to the popular clothing concept
- Increasing garment lifespan: creative solutions to allow aesthetic changeability
- Decreasing the technological lifespan: allowing for disposability

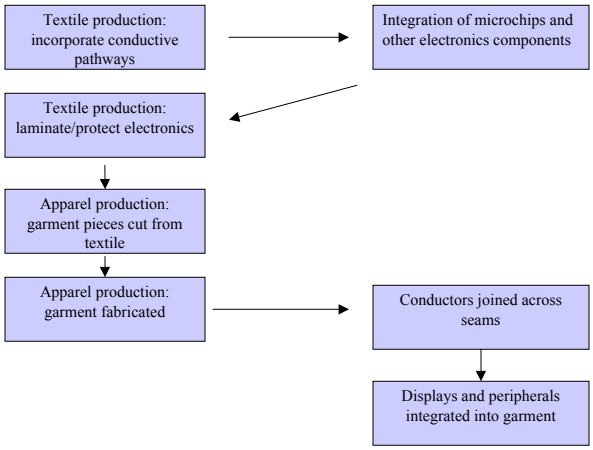
Commercial Production

- The problem: apparel factories are not equipped to handle electronics, electronics factories are not equipped to handle apparel.
- Current solution: apparel factories learn to encapsulated electronic units into garments with minimal integration (pockets, conduits for wires)

Commercial Production cont.

- Higher level integration: to integrate directly into textiles, production processes must be integrated, similarly to existing cut-and-sew processes.
- Weaving/knitting processes: incorporate conductive pathways, create pattern shapes at the textile level

Example Production Scenario



Some Garment Manufacture Possibilities

- Sewing
- Sealing:
  - Thermal welding
  - Radio frequency
  - Ultrasonic
- Molding
  - Thermoplastic textiles
  - Thermoplastic webs and films
  - Sprayed fibers
- 3-D Textile formation

Resources

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