U-SIT And Think News Letter - 79

Unified Structured Inventive Thinking is a problem-solving methodology for creating unconventional perspectives of a problem, and discovering innovative solution concepts, when conventional methodology has waned. Heuristic Innovation is an extension of USIT with continued simplification.

Subject Keys

PD = Problem definition
H = **Heuristics**
T = Theory
M = Metaphors
A = **Analysis**
BH = Brain hemispheres
EX = **Examples**

Dear Readers:

- This mini-lecture continues the discussion and demonstration of the simplification heuristic. It starts by addressing the conclusions developed in the lecture that did not agree with observation.
- If you have ways to make ice cubes under different growing conditions, and can photograph the results, please share them with us.

Mini USIT Lecture – 77

Heuristics

SIMPLIFICATION

In my opinion, the most important problem-solving heuristic is simplification. It is probably unnecessary to over emphasize the point because the readership of this news letter is composed predominately of professional problem solvers. I trust that these lectures can raise our appreciation of the heuristic and improve our practice of using it. Cognizance of simplification usage can improve the clarity of our thinking.

On the Formation and Characterization of Ice Cubes

As tallied in the last lecture of this 'ice-cube formation' series, as many as 12 simplifications have been used. There may be others used subconsciously that I've not noticed.

Fig. 1. Photograph of my ice cube.

This series, which I've touted as a demonstration of the simplification heuristic, ended on a questionable note in the last lecture. Of particular concern was the prediction of frozen-in slush appearing in the upper region of an ice cube, which appeared to be invalid on examining a real ice cube that I made (Fig.1).

In the first lecture (NL_77) eight configurations of frozen-in slush were posed but not all were explained. One not explained, which might fit this situation, showed an opaque

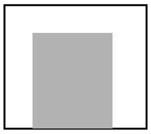

Fig.2 (From NL_77 Fig. 5b with no explanation)

region surrounded on all sides except the bottom by a clear region (Fig. 5b) shown in Fig. 2.

On comparing these two figures I realized that a major assumption mentioned in NL_77 had been overlooked when explaining the eight suggested configurations of opaque and clear regions. My comment in that lecture was: *“As a result of the tray resting on a solid shelf, the bottom water may cool more quickly; liquid-to-tray-to-shelf thermal conductivity should be greater than liquid-to-air conductivity (for good refrigerator design).”* At issue here are the paths for heat transfer from a forming ice cube.

Could it be that relative thermal conductivity of heat flowing through the top, the sides, and the bottom of a freezing ice cube can be significant? Mathematically, this is a boundary-value problem. But that’s too advanced a topic for this stage in addressing our problem. We are in the initial phase of phenomenological understanding of a problem situation. Later, after forming a plausible overview of the system, we would consider such analysis.

So, once again, let’s simplify the problem. There are three obvious paths for heat transfer by conduction: Ice-to-air at the top of the ice, ice-to-tray wall–to–air on its sides, and ice-to-tray bottom-to-solid on its bottom. Solid on the bottom, that supports the tray, might involve a layer of frost depending on the condition of the cooling chamber. The bottom support may be a shelf with many holes (mine is). In the holes the path is ice-to-tray-to-air.

On first thought, it might seem that the rate of heat through these three paths would be through the bottom as the fastest, the sides second, and the top the slowest. Can this be true?

The interesting thing to note is that the area composing the top and sides, and parts of the bottom of an ice tray, are in direct contact with air. This area is several times that of tray-to-solid contact area (especially when the solid is a shelf having many holes). Hence, air offers the largest area for escape of heat. But air is a thousand times less dense than the tray material with consequential lower effective heat conductivity and capacity. Presumably heat that passes through the tray-to-solid at the bottom is extracted into the refrigerator cooling system without passing through air. This was true in old-style refrigerators. My refrigerator has plastic shelves with holes in them and they rest on four small plastic supports. They don’t appear to be designed for optimum heat flow to the walls of the freezer compartment.

Another thing to note is that the heat escaping through the sides and top are rate limited by the thermal resistance of convective heat transfer that couples air-to-solid through the thin, nearly stagnant boundary layer of air. Since the air is basically the same on the sides and top of the ice tray the rate of heat loss through these two paths will differ mainly as a result of any difference in thermal resistance from ice-through boundary layer and ice through solid tray material and then through boundary layer (left-hand and right-

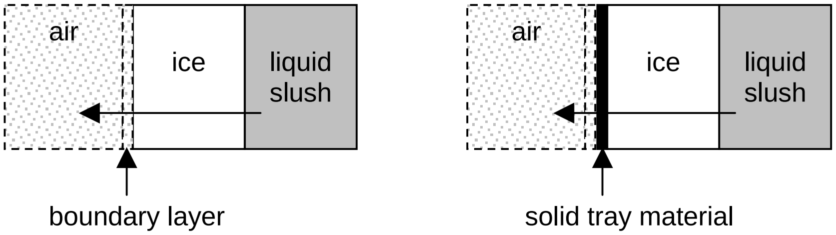

Fig. 3. Heat loss paths from liquid slush, through ice, through the boundary layer, and into surrounding air (left-hand sketch), with a layer of solid tray material inserted in the right-hand sketch. The heat flow paths are indicated by horizontal arrows.

hand drawings respectively, in Fig. 3).

Some refrigerators have metal ice-cube trays and some have plastic trays. A typical plastic used in ice-cube trays and heat exchangers is polypropylene. Polypropylene has very high thermal conductivity (and low heat capacity) so that the effective thermal resistance for conductive heat transfer to external gas is nearly the same for steel, aluminum, or polypropylene containers (http://www.segerfrojd.se/ppvsmetal.htm). This leads me to the generalization that the two paths shown in Fig. 3 have essentially the same heat transfer rates per unit cross-sectional area of flow path.

If we simplify the analysis by assuming that the per-area heat transfer rate does not differ much on all sides of a forming ice cube, then heat-flow path-length and ‘cube’ shape become the next consideration. Cube was put in quotation marks because the ‘cubes’ my refrigerator make are not literal cubes. This is evident in the photograph of my ice ‘cube’ (Fig. 1) and the photograph of the underside of its ice tray (Fig. 4).

To better understand the ice-‘cube’ in Fig. 1, I’ll simplify the picture as shown in Fig. 5. From the trapezoidal shape of the ice-‘cube’ in Fig. 5, and the assumption that heat flow per unit area coupling to air through the stagnant boundary layer is not significantly different on the top of the ice or on the surface of the tray, we can deduce why the frozen slush has the shape and location shown.

ig. 4. Upper photograph shows interior of the ice-tray section of a refrigerator. Note rectangular holes in the shelves. The right-hand photograph is of an up-turned ice tray showing the non-cubic shape of the ice-cube cells.

Notice, in Fig. 5, that the frozen slush has a similar shape as the ice-‘cube’ itself. The side BC is parallel to the top of the ice-‘cube’, the side DE is parallel to that side of the ‘cube’, the bottom GF is nearly parallel to its bottom, and the side AG is tilted a few degrees from parallel to that side of the ‘cube’. Now imagine the sides CD, EF, AG, and AB as truncations of a shape similar to the ‘cube’. I propose that these ‘truncations’ could occur by more heat escaping, per unit time, from the corners of the ‘cube’ than from its flat

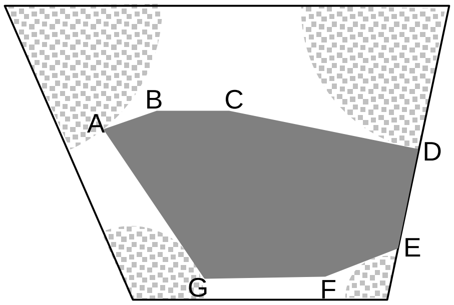

Fig. 5. Simplification of Fig. 1. Clear areas are ice, the dark gray area is frozen slush. Gray-dotted circular arcs are heat-flow regions affected by corners of the freezing ice.

surfaces. The regions shown as gray-dotted circular segments emphasize how heat escaping from their volumes have more surface area on the outside of the ‘cube’ for heat to escape than do the more central, flat surface areas of the freezing slush. This accounts for the general shape of the frozen slush. What about its location?

The frozen slush has more clear ice above it than below it. This indicates that water froze more quickly near the upper surface than the lower surface of the ‘cube’. When we note that the ice-tray rests on a plastic shelf, it is clear that the path for heat escaping through the bottom has the shelf as added resistance to flow. Furthermore, the upper surface of the ‘cube’ is larger than the bottom, which enables relatively more heat loss. What’s going on along the side DE?

Obviously, the surface represented by DE is where heat was lost more slowly and consequently where slush froze last. Note in Fig. 4 that the sides DE are the inner sides in a row of cells in an ice tray. In this region, bounded by the top of the tray (between two rows of cells), the DE-sides of the ‘cubes’, and the supporting shelf, air is less free to circulate. This reduces convection, which is the main mechanism for replacing warmer air with colder air.

For the moment, I claim that the above explanation of the opaque and clear regions of the ice-‘cube’ in Fig. 1 is a plausible explanation. (I welcome your comments in agreement or to the contrary.)

And, for the moment, I see no need to invoke viscosity of cold water as an observable effect in ice-‘cube’ formation. It appears now that heat flow paths for heat to escape freezing slush are more important to consider.

The overall thermal difference that drives freezing in an ice cube tray is the difference in 0 ^{o}C temperature within the ice cube and the less than 0 ^{o}C within the freezer chamber.

New experiments come to mind to better understand cooling rate. But how can they be done in the refrigerator in my kitchen, and without instrumentation? It would be interesting, at least, to compare the results of rapid versus slow freezing of slush in forming an ice-‘cube’.

Properties and Formation of Gedanken Ice	
Simplification	Conclusion
Heat flows down a thermal gradient	1. During ice-cube growth its central water is always warmer than the water at its outer surfaces, otherwise no heat could be extracted from the water by conduction. 2. Thus, in an ice tray, colder water will line the fringes of each cell while warmer water lies toward the center of each cell's volume.
Anomalous expansion of water increases its buoyancy as it nears 0^o C.	3. While cooling below 4 ^{o}C, water becomes increasingly buoyant, at the bottom and side walls of an ice tray, as compared with the central water. 4. Thus, a tendency exists for convective flow of water.
Viscosity of water increases with cooling	5. While freezing ensues, part of the ice forming on the outer surfaces will adhere to the solid walls, and to preformed ice, and part will mix with the viscous water to become slush, a mixture of ice particles and unfrozen water. 6. Freezing slush accumulates at the center of an ice-tray cell and becomes totally entrained within a newly formed ice cube.
Solubility limit of air in ice is much lower than that in ice water	7. Air dissolved in water is excluded for ice that forms from this water. 8. Air appears as bubbles in the cold water bounding the forming ice.
Refractive indices of water, ice, and gas	9. Slush composed of particles of ice and bubbles of gas in ice water is only slightly discernable as a result of differing indices of refraction in ice, gas, and water.
Multiple scattering of light weakens its intensity.	10. Frozen slush contains small bubbles and particles of ice that cause multiple scattering of transmitted and reflected light giving slush a lower contrast relative to its surrounding ice. This makes slush readily visible.
Details of nucleation are ignored.	11. It is assumed that air bubbles and ice formation from water simply occur with out concern for molecular details such as nucleation.
Dissolved gas is not identified.	12. Species of gas molecules are ignored. The words air and gas are used interchangeably as generic references.
Third dimension of ice ignored	13. Showing ice cube in cross section as a square simplifies visualization of heat flow.
Surrounding air is the major heat sink for a tray of freezing ice.	14. A stagnant boundary layer limits the flow of heat into surrounding air as a result of the high resistance of the stagnant boundary layer of air.
Boundary-layer air is essentially the same next to ice or tray walls.	15. Heat flow rates per unit cross-sectional area of flow path are nearly equal. (This does not consider path length.)
Plastic ice trays have high enough thermal conductivity so that differences in heat flow rate through ice versus ice plus tray wall can be ignored.	16. Rate of heat loss to the surrounding air, per unit cross-sectional area of flow path, is essentially the same on both the top and sides of a freezing 'cube'. (This does not consider path length.)

To be continued …

Other Interests

1. Have a look at the USIT textbook, “Unified Structured Inventive Thinking – How to Invent”, details may be found at the Ntelleck website: www.u-sit.net
2. See also “Heuristic Innovation”, which further simplifies USIT.

Publications	Language	Translators	Available at …
1. Textbook: Unified Structured Inventive Thinking – How to Invent	English	Ed Sickafus (author)	www.u-sit.net
2. eBook: Unified Structured Inventive Thinking – an Overview	English	Ed Sickafus (author)	www.u-sit.net
	Japanese	Keishi Kawamo, Shigeomi Koshimizu and Toru Nakagawa	www.osaka-gu.ac.jp/php/nakagawa/TRIZ/
	Korean	Yong-Taek Park	www.ktriza.com/www/usit/register_form.htm
“Pensamiento Inventivo Estructurado Unificado – Una Apreciación Global”	Spanish	Juan Carlos Nishiyama y Carlos Eduardo Requena	www.u-sit.net
3. eBook “Heuristic Innovation – Engaging both brain hemispheres in rapidly solving technical problems for multiple solution concepts”	English	Ed Sickafus (author)	www.u-sit.net
4. U-SIT and Think Newsletter	English	Ed Sickafus (Editor)	www.u-sit.net
	Japanese	Toru Nakagawa and Hideaki Kosha	www.osaka-gu.ac.jp/php/nakagawa/TRIZ/
	Korean	Yong-Taek Park	www.ktriza.com.
Mini-lectures from NL_01 through NL_74	Spanish	Juan Carlos Nishiyama y Carlos Eduardo Requena	www.u-sit.net click on Registration

Please send your feedback and suggestions to Ntelleck@u-sit.net and visit www.u-sit.net

To be creative, U-SIT and think.