LCD In-Cell Touch

Geoff Walker – NextWindow
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Agenda

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- Touch Market [2]
- Conclusions [1]
- Appendix [3]

[34] = Total number of content slides
Bay-Area SID Chapter

This Chapter needs your help! We need people who…
- Have some time available
- Want to get involved

If you’re interested, please contact me or Dave Armitage after the presentation
Multi-Touch

Sources: Engadget, Do Device and Good Times & Happy Days
Multi-Touch

- **Multi-touch** is defined as the ability to recognize two or more simultaneous touch points.
- Multi-touch was invented in 1982 at the University of Toronto *(not by Apple in 2007!)*
- “Pinching” gestures were first defined in 1983 *(not by Apple in 2007!)*
- Windows 7 (released 10/22/09) supports multi-touch throughout the OS.
- Windows 7 is structured to support an unlimited number of simultaneous touch points.
Multi-Touch Architecture

- **Application**
  - Capable of decoding multiple streams of moving points and taking actions in response

- **Operating System**
  - Capable of forwarding multiple streams of moving points (and acting on a defined subset of them)

- **Touchscreen Controller & Driver**
  - Capable of delivering sets of simultaneous points to the OS

- **Touchscreen Sensor**
  - Capable of sensing multiple simultaneous points
## Multi-Touch Technologies

<table>
<thead>
<tr>
<th>Touch Technology</th>
<th>Multi-Touch Capable? (#)</th>
<th>Win-7 Logo Capable?</th>
<th>Commercial MT Product Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Capacitive</td>
<td>Yes (unlimited)</td>
<td>Yes</td>
<td>Apple iPhone; Dell Latitude XT</td>
</tr>
<tr>
<td>Digital Resistive</td>
<td>Yes (unlimited)</td>
<td>Yes</td>
<td>JazzMutant Music Controller</td>
</tr>
<tr>
<td>LCD In-Cell (all forms)</td>
<td>Yes (unlimited)</td>
<td>Yes</td>
<td>Sharp Netbook</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>Yes (unlimited)</td>
<td>Yes</td>
<td>Microsoft Surface</td>
</tr>
<tr>
<td>Optical</td>
<td>Yes (~4)</td>
<td>Yes</td>
<td>HP TouchSmart</td>
</tr>
<tr>
<td>Traditional Infrared (“XYU” IR from Elo)</td>
<td>Yes (~4)</td>
<td>Yes</td>
<td>Products in development (2010)</td>
</tr>
<tr>
<td>Surface Acoustic Wave (“XYU” SAW from Elo)</td>
<td>Yes (2)</td>
<td>Yes</td>
<td>Products in development (2010)</td>
</tr>
<tr>
<td>Waveguide Infrared (RPO)</td>
<td>Yes (2)</td>
<td>Yes</td>
<td>Products in development (2010)</td>
</tr>
<tr>
<td>Analog Resistive</td>
<td>No</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>No</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>No</td>
<td>No</td>
<td>--</td>
</tr>
</tbody>
</table>
"If you can only manipulate one point ... you are restricted to the gestural vocabulary of a fruit fly. We were given multiple limbs for a reason. It is nice to be able to take advantage of them."

Bill Buxton, 2008
Principal Researcher,
Microsoft Research
LCD In-Cell Touch

Source: TMD
Three Different Technologies Used In LCD In-Cell Touch

- **Light-sensing or “optical”**
  - Addition of a photo-transistor (photocell) into each pixel
  - Works with finger, stylus, light-pen or laser pointer; also works as a scanner

- **Switch-sensing or “voltage-sensing” or “resistive”**
  - Addition of micro-switches for X & Y into each pixel
  - Works with finger or stylus, within damage limits of LCD

- **Capacitive-sensing or “charge-sensing”**
  - Addition of electrodes into each pixel for capacitive sensing
  - Works with finger-only, within damage limits of LCD

AUO: Hybrid capacitive + switch-sensing
## Three Different Physical Integration Methods Used In LCD “In-Cell” Touch

<table>
<thead>
<tr>
<th>Term</th>
<th>Integration Method</th>
</tr>
</thead>
</table>
| **In-Cell** | Touch sensor is *physically inside the LCD cell*  
Touch sensor can be:  
• Light-sensing photo-transistors (optical)  
• Micro-switches (switch-sensing)  
• Capacitance-sensing electrodes (capacitive) |
| **On-Cell** | Touch sensor is an X-Y array of ITO conductors  
*on the top or bottom surface of the color filter substrate*  
• Capacitive-only (1) |
| **Out-Cell** | Standard touchscreen *laminated directly on top of the LCD* during manufacture  
• Key difference: An additional piece of glass is required  
• Typically only projected capacitive or analog resistive  
• New term coined by AUO – *Since this term hasn’t entered common usage yet, some LCD manufacturers still refer to this configuration as on-cell* (2) |

(1) CMO persists in labeling their on-cell capacitive (on top of the color filter glass) as “in-cell” capacitive.  
(2) LGD’s 6.4-inch “on-cell capacitive” at SID 2009 was actually a laminated cover-glass with ITO patterning on the under-side.
LCD In-Cell Touch Fundamental Issues

- **LCD design changes**
  - Modifying the backplane or frontplane of a single LCD to add in-cell touch costs >$1M due to masking
  - If touch isn’t required in every LCD, will LCD manufacturers be willing to make touch & non-touch versions of many different LCDs?

- **OEM second-sourcing**
  - Almost all OEMs have multiple sources for their LCDs; in-cell introduces a big new source of potential incompatibility

- **Choice of touch technologies**
  - Different applications require different touch technologies; it’s almost never “one size fits all”
Light-Sensing…1

- **Principle**
  - Photo-transistors see shadow of finger in bright light or reflection of backlight on finger in dim light

- **History**
  - TMD was first to announce the concept on 4/03
    - First to auto-switch between shadow & reflection
    - No announced commercialization date
  - Sharp announced the same concept on 8/07
    - Sharp has one product in current production
  - Planar published a paper on 8/07 with AUO showing a prototype of the same concept
  - LG.Philips announced the same concept in an automotive LCD at FPD/International on 10/07

(Conceptual illustration)
Sample captured image on 2.6” VGA (300 ppi)
Source: Sharp
Light-Sensing…2

- Another conceptual illustration

- Size range
  - ♦️ 3” to 3x”
  - ● AUO is working on 30”- 40” with 1 sensor/9 pixels (finger-resolution)
  - ♦️ Technically there is no upper size limit
Light-Sensing…3

- **Suppliers**
  - AUO, CMO, CPT, LGD, Samsung, Sharp, Sony, TMD…
  - AUO says they’ve been in “mass production” on 3” & 4.3” in-cell optical since 2008, but there’s no sign of any end-user products…

- **Advantages**
  - Integration, size, thickness, weight, ID
  - Unlimited multi-touch (controller-dependent)
  - Conceptually high performance
    - Low parallax error (assuming no cover glass)
    - Very accurate & linear touch-point data
    - Potentially higher resolution than LCD through interpolation
  - Can work as a scanner
  - Capable of detecting the difference between hover & touch
    - Problematic in low ambient
Disadvantages

- Touching a black image doesn’t work in low ambient light
- A cover-glass is desirable to protect the LCD, but a cover-glass reduces touch sensitivity due to the spacing between the finger and the photo-transistor
  - Optical bonding helps (at additional cost & lower yield)
  - Harder LCD top-polarizer is the best solution to this problem
- Smaller aperture causes light loss (inefficient)
- Significant processing power is required due to image processing in every sensing cycle
- Cost (?) – rumors of significant cost problems…
Potential solutions to the “can’t touch black” problem

- Add an IR light source (e.g., backlight LEDs), and make in-pixel light sensors IR-sensitive
  - IR goes through the LCD and reflects off the finger
  - Sharp did this in their netbook “touchpad LCD”

- Add IR edge-lighting on a cover glass and use FTIR
  - Planar created IP on this idea\(^{(1)}\) in 2004-2007, then sold it to a [small-medium?] LCD manufacturer in 2009, which will probably prevent all others from using the idea

Light-Sensing…6

- **Controller functions**
  - Too much horsepower required for on-glass silicon
    - Analog-to-digital conversion
    - Position determination
    - Image processing & motion recognition (phone vs. Windows)

- **Applications**
  - Mobile devices are clearly the initial target
  - LGD & e-Ink showed an e-book reader with in-cell optical touch at SID 2009
  - AUO & SiPix announced a similar concept at Display Taiwan 2009
Light-Sensing…7

Sharp’s PC-NJ70A netbook (5/09)

- Optical in-cell touch in 4” CG-silicon 854x480 touchpad LCD (245 dpi!)
  - 1 sensor per 9 pixels
  - LED backlight
  - Stylus & 2-finger multi-touch
  - Scanning (shape recognition)
  - Touch surface = ??
  - Japan-only; $815

Problems
- Needed IR from backlight
- **S L O W** (25% of typical touchpad speed)

First use of in-cell optical touch in a commercial product…?
Light-Sensing...8

Segmented characters indicate very slow response

Source: AkihabaraNews.com
Light-Sensing...9

Standard retractable PDA-style pen

Source: NetbookChoice.com

Source: AkihabaraNews.com

Source: Sharp
Switch-Sensing…1

- **Principle**
  - Pressing LCD surface closes micro-switches in each pixel

- **Size range**
  - 3” to 26” (AUO’s stated maximum)
  - Limited by RC-loading of (and space for) connecting traces

- **Suppliers**
  - AUO and Samsung

- **Controller**
  - Relative simplicity potentially allows integration into LCD driver
  - Needs “isolated drive & scan”, like Stantum’s digital resistive
Switch-Sensing...2

- Samsung’s design (AUO’s is very similar)

Source: Samsung
Advantages

- Integration, size, thickness, weight, ID
- Unlimited multi-touch (controller-dependent)
- Low parallax error; very accurate & linear data; can be same resolution as LCD
- Totally independent of ambient, back or front-lighting
- Simplest controller of the three in-cell types
Switch-Sensing...4

- **Disadvantages**
  - Switch-sensing definitely won’t work with a cover glass, so the LCD can easily be damaged
    - AUO’s current spec is only 100K touches at <40 grams! – although it’s unclear if it’s limited by the LCD surface or the ITO cracking
    - Typical resistive touchscreen spec is 1M touches (4-wire) or 30M touches (5-wire) at ~80 grams
    - Harder LCD top-polarizer may solve this problem
  - Finite (non-zero) activation force, which can make multi-touch gestures more difficult to perform
  - Smaller aperture causes light loss (inefficient)
  - Liquid-crystal pooling can be visually distracting

- **Applications**
  - Mobile is clearly the initial target; others TBD
Capacitive-Sensing...1

- **Out-cell**
  - Laminated capacitive or resistive touchscreen

![Diagram of Touchscreen Construction](image)

Source: Cando
Capacitive-Sensing...2

- **On-cell**
  - Capacitive touchscreen sensor on color filter glass
  - LCD with touchscreen ITO sensor deposited on top of color filter glass, under polarizer (most common)
  - Color filter with touchscreen ITO sensor deposited between color filter glass and color filter

[Diagram of LCD structure]

Source: DisplaySearch

Source: Cando
Capacitive-Sensing...3

- **In-cell**
  - Capacitive-sensing ITO electrodes added inside the LCD cell

- **Principle**
  - Body capacity to ground changes capacitance between sensor CS and bottom electrode
  - No pressure is required
  - Similar to projected capacitive

Source: LG Display
A different in-cell design: Integritouch (Sweden)

- Integritouch’s patented method of switching the LCD’s existing internal electrodes to become projected-capacitive touch-screen electrodes during the refresh cycle
- Patent WO 2005/036510
- No real traction to date
  - LCD fab’s N.I.H.?
  - Are there enough significant advantages?
Capacitive-Sensing...5

- **Size range**
  - 3” to 24”
  - AUO has demoed 12” & 15”; they say their maximum will be 24”

- **Controller**
  - Same concept as standard “all points addressable” projected-capacitive controllers, but unique to each LCD manufacturer
  - Some controller suppliers are partnering with LCD manufacturers (e.g., AUO/Cando & Cypress)

- **Advantages (in-cell & on-cell)**
  - Integration, size, thickness, weight, ID
  - Unlimited multi-touch (controller-dependent)
  - Totally independent of ambient, back or front-lighting
  - Potentially higher resolution than LCD through interpolation
Disadvantages (in-cell & on-cell)

- Finger-touch only; no stylus
- In-cell capacitive sensing won’t work well with a cover glass, so the LCD can easily be damaged
- All forms of capacitive sensing are subject to electrical noise; successful integration into the LCD can be very difficult, especially as the LCD size increases
- Significant processing power is required in the controller in order to achieve reasonable performance
  - Same as in-cell optical
- Smaller aperture ratio causes light loss (inefficient)
- Liquid-crystal pooling can be visually distracting
Capacitive-Sensing…7

- **Applications**
  - Mobile phones, netbooks & notebooks; maybe monitors & AiOs

- **Suppliers**
  - AUO, CMO, CPT, LGD…
    - At LCD fab for in-cell
    - At color filter fab (e.g., AUO/Cando) for on-cell

Source: AUO
Capacitive-Sensing...8

Photos taken at FPD 2008 in Yokohama

AUO

LGD

AUO

AUO
Capacitive-Sensing...9

LG Display 13.3” in-cell capacitive At SID 2009

Attempt to draw a grid of straight lines...

Lots of pooling and ink lag!
Technology Comparison
# Technology Comparison

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Optical</th>
<th>Switch</th>
<th>Capacitive (in-cell &amp; on-cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size limit</td>
<td>Unlimited</td>
<td>26”</td>
<td>24”</td>
</tr>
<tr>
<td>Input device</td>
<td>Finger, stylus, light-pen</td>
<td>Finger, stylus</td>
<td>Finger</td>
</tr>
<tr>
<td>Touch force required</td>
<td>None</td>
<td>Some</td>
<td>None</td>
</tr>
<tr>
<td>Cover glass possible</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Durability</td>
<td>High with cover glass</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>True flush surface (“zero bezel”)</td>
<td>Yes with cover glass</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Transmissivity loss</td>
<td>Aperture</td>
<td>Aperture</td>
<td>Aperture plus ITO (on-cell)</td>
</tr>
<tr>
<td>EMI sensitivity</td>
<td>None</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>Ambient light sensitivity</td>
<td>High</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Flexible substrate</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Controller complexity</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

Red-yellow-green color ratings are relative within the three in-cell technologies, not within all touch technologies.
Touch Market

Source: Gizmodo
LCD In-Cell Forecast by Screen Size

DisplaySearch’s 2009 Forecast

In-cell shipments as a percentage of the total number of touchscreens shipped each year

Size Range
- 15.x-19.x"
- 10.x-14.x"
- 5.x-9.x"
- 3.x-4.x"
- <3"

Units (Millions)
- 2009: 0.1%
- 2010: 0.2%
- 2011: 0.6%
- 2012: 1.0%
- 2013: 1.3%
- 2014: 1.8%
- 2015: 2.3%
Touch Technology Forecasts for Phones, Notebooks & Monitors/AiOs

DisplaySearch’s & Morgan Stanley’s Forecast for 2013

- **Touch Technology**
  - In-Cell
  - Other
  - Optical
  - Pro-Cap
  - Resistive

**Morgan Stanley**
“Taiwan TFT LCD: Opportunities In Touch” (6/25/09)

(DS = DisplaySearch) (MS = Morgan Stanley)
Conclusions

Source: CG4TV
# There Is No Perfect Touch Technology!

<table>
<thead>
<tr>
<th>Technology</th>
<th>Major Advantage</th>
<th>Major Flaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Resistive</td>
<td>Low cost</td>
<td>Low durability</td>
</tr>
<tr>
<td>Digital Resistive</td>
<td>Multi-touch</td>
<td>Low resolution</td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>Touch sensitivity</td>
<td>High drift</td>
</tr>
<tr>
<td>Projected Capacitive</td>
<td>Multi-touch</td>
<td>Finger-only</td>
</tr>
<tr>
<td>Surface Acoustic Wave</td>
<td>Durability</td>
<td>Hard to seal</td>
</tr>
<tr>
<td>Traditional Infrared</td>
<td>Reliability</td>
<td>High cost</td>
</tr>
<tr>
<td>Waveguide Infrared</td>
<td>Low cost</td>
<td>Contamination</td>
</tr>
<tr>
<td>Camera-Based Optical</td>
<td>Scalability</td>
<td>Profile height</td>
</tr>
<tr>
<td>Acoustic Pulse Recognition</td>
<td>Any touch-object</td>
<td>No touch &amp; hold</td>
</tr>
<tr>
<td>Bending Wave</td>
<td>Any touch-object</td>
<td>No touch &amp; hold</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>3D substrate</td>
<td>No multi-touch</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>Multi-touch</td>
<td>Rear projection</td>
</tr>
<tr>
<td>LCD In-Cell (Optical)</td>
<td>Integration</td>
<td>Sensitivity</td>
</tr>
<tr>
<td>LCD In-Cell (Capacitive)</td>
<td>Integration</td>
<td>Durability</td>
</tr>
<tr>
<td>LCD In-Cell (Switch-Sense)</td>
<td>Integration</td>
<td>Durability</td>
</tr>
</tbody>
</table>
Thank You!

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1-408-506-7556 (mobile)
gwalker@nextwindow.com
Appendix

Source: Vissumo
# 2008 Overall Touch Market

<table>
<thead>
<tr>
<th>Technology</th>
<th>2008</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Small-Med (&lt;10”)</td>
<td>Large-Area (&gt;10”)</td>
<td>TOTAL</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Revenue</td>
<td>Units</td>
<td>Revenue</td>
<td>Units</td>
</tr>
<tr>
<td>Resistive</td>
<td></td>
<td>$1,140M</td>
<td>325M</td>
<td>$684M</td>
<td>40M</td>
</tr>
<tr>
<td>Surface acoustic wave</td>
<td></td>
<td>$4.7M</td>
<td>0.1M</td>
<td>$185M</td>
<td>2.8M</td>
</tr>
<tr>
<td>Surface capacitive</td>
<td></td>
<td>$0.2M</td>
<td>0M</td>
<td>$168M</td>
<td>2.0M</td>
</tr>
<tr>
<td>Infrared</td>
<td></td>
<td>$4.5M</td>
<td>0.1M</td>
<td>$128M</td>
<td>1.0M</td>
</tr>
<tr>
<td>Mainstream</td>
<td></td>
<td>$1,150M</td>
<td>325M</td>
<td>$1,165M</td>
<td>46M</td>
</tr>
<tr>
<td>Emerging</td>
<td></td>
<td>$462M</td>
<td>31M</td>
<td>$55M</td>
<td>0.8M</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>$1,612M</td>
<td>356M</td>
<td>$1,220M</td>
<td>47M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Revenue</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small-Medium</td>
<td>57%</td>
<td>88%</td>
</tr>
<tr>
<td>Large-Area</td>
<td>43%</td>
<td>12%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

All market size charts are based on DisplaySearch’s 2009 “Touch-Panel Market Analysis” with adjustments.
# 2008 Touch Market By Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>2008 Revenue</th>
<th>2008 Share</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Resistive **</td>
<td>$1,824M</td>
<td>64%</td>
<td>30% = stationary</td>
</tr>
<tr>
<td>Projected Capacitive</td>
<td>$470M</td>
<td>17%</td>
<td>3% = stationary</td>
</tr>
<tr>
<td>Surface Acoustic Wave (SAW) **</td>
<td>$190M</td>
<td>6.7%</td>
<td>Most &gt; 10”</td>
</tr>
<tr>
<td>Surface Capacitive **</td>
<td>$168M</td>
<td>5.9%</td>
<td>Most &gt; 10”</td>
</tr>
<tr>
<td>Traditional Infrared **</td>
<td>$133M</td>
<td>4.7%</td>
<td>Most &gt; 10”</td>
</tr>
<tr>
<td>Camera-Based Optical</td>
<td>$40M</td>
<td>1.4%</td>
<td>All &gt; 10”</td>
</tr>
<tr>
<td>Acoustic Pulse Recognition (APR – Elo)</td>
<td>$2M</td>
<td>0.1%</td>
<td>All &gt; 10”</td>
</tr>
<tr>
<td>Dispersive Signal Technology (DST – 3M)</td>
<td>$2M</td>
<td>0.1%</td>
<td>All &gt; 30”</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>$2M</td>
<td>0.1%</td>
<td>All &gt; 30”</td>
</tr>
<tr>
<td>Force Sensing (Vissumo)</td>
<td>$1M</td>
<td>0%</td>
<td>Start-up</td>
</tr>
<tr>
<td>Digital Resistive</td>
<td>0</td>
<td>0%</td>
<td>No controllers</td>
</tr>
<tr>
<td>Waveguide Infrared (RPO)</td>
<td>0</td>
<td>0%</td>
<td>No customers</td>
</tr>
<tr>
<td>LCD In-Cell (all forms)</td>
<td>0</td>
<td>0%</td>
<td>No shipments</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$2,832M</strong></td>
<td><strong>100%</strong></td>
<td></td>
</tr>
</tbody>
</table>

- 4 mainstream touch technologies** ........ 82%
- #2 new kid on the block (pro-cap) ........ 17%
- Remaining emerging technologies .......... 1%!
# 2008 Touch Market By Application

<table>
<thead>
<tr>
<th>Application</th>
<th>2008 Revenue</th>
<th>2008 Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile Phone</td>
<td>$ 801M</td>
<td>28.3%</td>
</tr>
<tr>
<td>Other</td>
<td>$ 311M</td>
<td>11.0%</td>
</tr>
<tr>
<td>Retail/POS</td>
<td>$ 222M</td>
<td>7.8%</td>
</tr>
<tr>
<td>Point of Information/Check-In</td>
<td>$ 211M</td>
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<tr>
<td>ATM/Financial</td>
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<td>Portable Navigation Device</td>
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<td>Game – Portable</td>
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<td>Medical</td>
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<td>Game – Casino</td>
<td>$  77M</td>
<td>2.7%</td>
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<tr>
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<td>2.5%</td>
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<tr>
<td>Ticketing</td>
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<tr>
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<tr>
<td>Printer/Office</td>
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<tr>
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<tr>
<td>Desktop/PC Monitor</td>
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<tr>
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<tr>
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<tr>
<td>Mini-Notebook</td>
<td>$   7M</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$2,832M</strong></td>
<td><strong>100%</strong></td>
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