Planting, Growing, and Pruning Trees: Connected Filters Applied to Document Image Analysis

Guillaume Lazzara, Thierry Géraud, Roland Levillain

EPITA Research and Development Laboratory (LRDE)

April 8, 2014

EPITA
GRADUATE SCHOOL OF COMPUTER SCIENCE

LRDE

Quotation

Reviewer 1:

I wasn't overly impressed with this paper
until I saw Figure 9.

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Hum...

We know that *mathematical morphology* can often look impressive...

...yet, today you just need to understand $\leq$ and $\subset$...

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C. Links between $(\ddot{\Theta}, \ddot{\blacktriangleleft})$ *and* $(\dot{\Theta}, \dot{\blacktriangleleft})$

The nodes of $(\dot{\Theta}, \dot{\blacktriangleleft})$ which are preserved in $(\ddot{\Theta}, \ddot{\blacktriangleleft})$ are the sup/max-generators of I, *i.e.*, the valued connected components $K \in \dot{\Theta}$ which contribute effectively to the (re)construction of I *via* their associated cylinder function C_K (see Formulae (13) and (17)). This property can however be expressed without directly considering the relations between I and the cylinder functions induced by $\dot{\Theta}$.

Property 6: Let $K = (X, v) \in \dot{\Theta}$. We have

$$(K \in \ddot{\Theta}) \Leftrightarrow ((K \in \overset{\trianglelefteq}{\bigtriangleup} \dot{\Theta}) \vee (K \neq \bigsqcup \overset{\trianglelefteq}{\bigtriangleup} K^{\downarrow})) \tag{28}$$

Proof: First note that $(\Omega, \perp)$ satisfies Formula (28). Let us now suppose that $K \neq (\Omega, \perp)$. If $K = (X, v) \in \bigtriangleup^{\trianglelefteq} \dot{\Theta}$, then for all $x \in X$, we have $I(x) = v$. If $K \neq \bigsqcup \bigtriangleup^{\trianglelefteq} K^{\downarrow}$, then, there exists $x \in X$ such that $I(x) = v$. The fact that $K \in \ddot{\Theta}$ then derives from Formula (13). If $K \notin \bigtriangleup^{\trianglelefteq} \dot{\Theta}$ and $K = \bigsqcup \bigtriangleup^{\trianglelefteq} K^{\downarrow}$, then for each $x \in X$, there exists $K' \in$

$$(\Theta, \trianglelefteq) \text{ is a upper-piecewise lattice.} \tag{29}$$

Proof: Let $K = (X, v) \in \bigtriangleup^{\trianglelefteq} \Theta$. It derives from Property 2 that $(K^{\uparrow}, \trianglelefteq)$ is a lattice. Since for any $x \in X$ where $(X, \trianglelefteq)$ is a lattice, $(x^{\uparrow}, \trianglelefteq)$ is still a lattice, $(\Theta, \trianglelefteq)$ is a upper-piecewise lattice. ■

As a corollary, we have the following property, related to the structure of the equivalence classes of $\sim_\theta$.

Property 8: Let $(V, \leqslant)$ be a lower-piecewise lattice. Let $K \in \Theta$, then

$$([K]_{\sim_\theta}, \trianglelefteq) \text{ is a lower-semilattice.} \tag{30}$$

Proof: Let $K = (X, v)$. Let $K' = (Y, u) \in \bigtriangleup^{\trianglelefteq} \Theta$ such that $Y \subseteq X$. From Property 7, $(K'^{\uparrow}, \trianglelefteq)$ is a lattice. Moreover we have $[K]_{\sim_\theta} \subseteq K'^{\uparrow}$. As $(V, \leqslant)$ is a lower-piecewise lattice, $(u^{\downarrow}, \leqslant)$ is a lattice. Let $(X, v_1), (X, v_2) \in [K]_{\sim_\theta}$. We have $X \subseteq \lambda_{v_1 \vee^{\leqslant} v_2}(I)$, and then, from Property (P3), $X \in \mathcal{C}[\lambda_{v_1 \vee^{\leqslant} v_2}(I)]$. Consequently, we have $(X, v_1 \vee^{\leqslant} v_2) \in [K]_{\sim_\theta}$, and the result follows. ■

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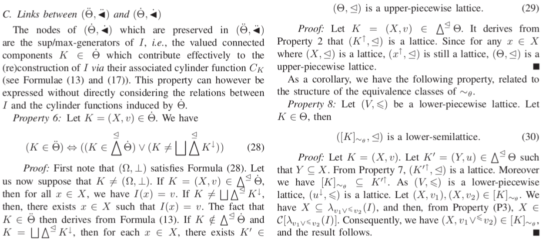

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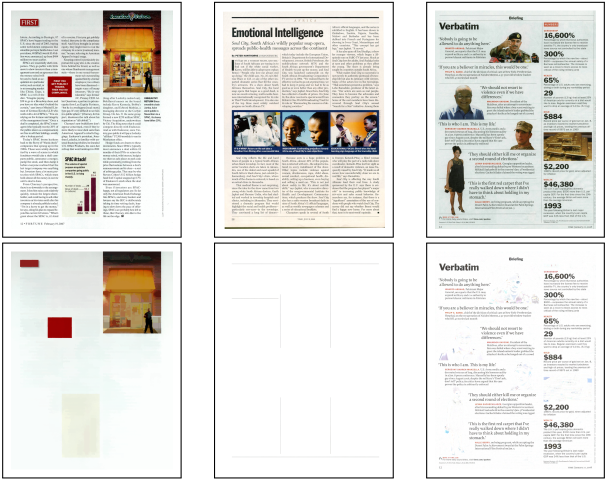
Fig. 9



Sample uses of connected operators. Top: input images; Bottom: **filtered** images (results).

The Meta Outline

Why this talk?	MM filters are good for DIA people!
Why is that interesting?	Connected filters are little known.
How does this work?	By planting, growing and pruning trees.
What can it be used for?	Denoising, image simplification, object identification, etc.

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Evangelization from the Church of Mathematical Morphology :-)

Three Messages from the Church

Regarding. . .

. . . Mathematical Morphology (MM)

Refresh your vision of MM $\rightarrow$ forget ε and δ!

. . . Connected Filters

Powerful, simple, and well-suited to DIA.

. . . Methodology

Advocate gray-level morphological strategies
(vs approaches based on “binarize first”).

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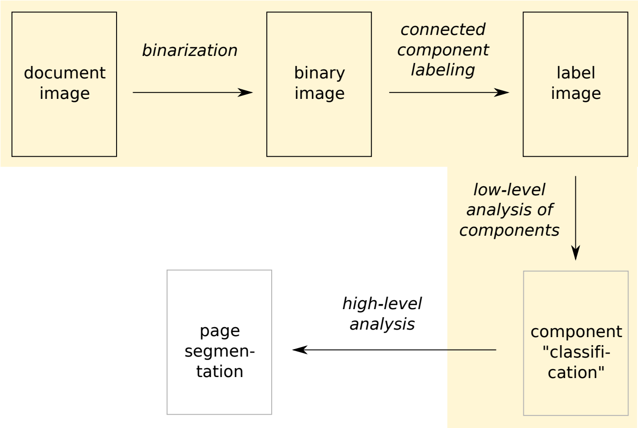

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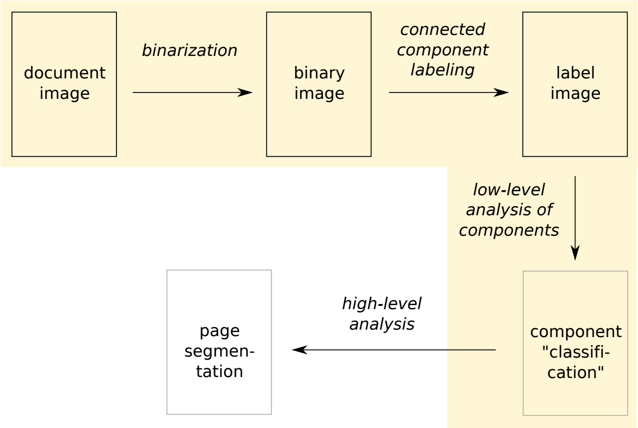
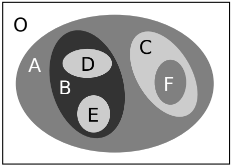


Starting by binarization is hell!

Components and Decomposition Principle

$u =$ 

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so connected components can be arranged into trees...

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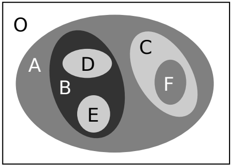
$u =$ 

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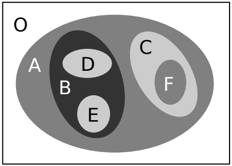
$u =$ 

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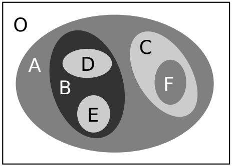
$u =$ 

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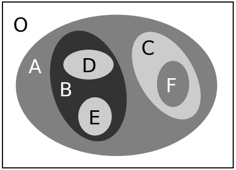
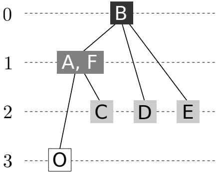
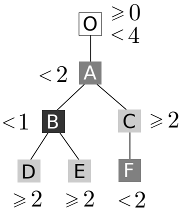


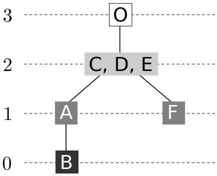
(a) image



(b) max-tree



(c) tree of shapes



(d) min-tree

Mathematical Morphology: Connected Operators

An interesting class of filters:

- Not based on structuring elements (so not like ε or δ)
- Considering all the connected components obtained by thresholding the image.
- Don't shift contours; don't create new ones.
- Intuitive, powerful, and efficient.
- Can be implemented as tree filtering.

Min/Max-Tree Implementation [Berger et al., 2007]

```
FIND-ROOT(x)
if zpar(x) = x then return x
    else { zpar(x) ← FIND-ROOT(zpar(x)) ; return zpar(x) }

COMPUTE-TREE(f)
for each p, zpar(p) ← undef
R ← REVERSE-SORT(f)   // maps R into an array
for each p ∈ R in direct order
    parent(p) ← p ; zpar(p) ← p
    for each n ∈ N(p) such as zpar(n) ≠ undef
        r ← FIND-ROOT(n)
        if r ≠ p then { parent(r) ← p ; zpar(r) ← p }
DEALLOCATE(zpar)
return pair(R, parent)   // a ''parent'' function

CANONIZE-TREE(parent, f)
for each p ∈ R in reverse order
    q ← parent(p)
    if f(parent(q)) = f(q) then parent(p) ← parent(q)
return parent   // a ''canonized'' parent function
```

⟵ tree computation (no code missing!)

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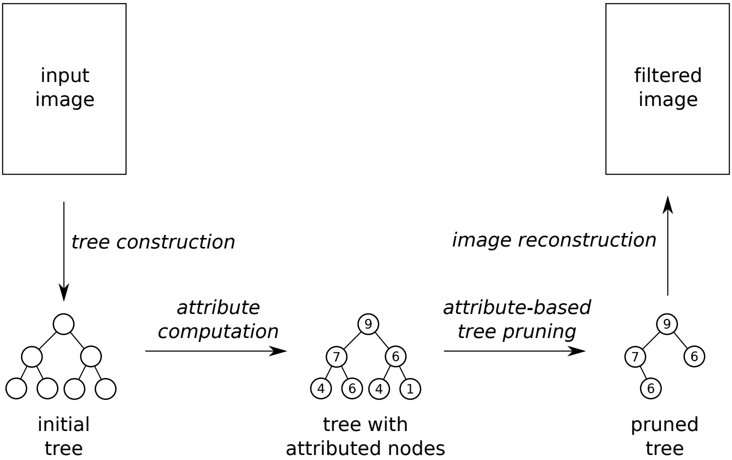
image filtering ⟶ add about 10 lignes of code...

Connected Operators as Tree Filtering



Tree Pruning and Morphological Operations

Various trees leading to various operators.

Pruning a max-tree	Algebraic opening.
Pruning a min-tree	Algebraic closing.
Pruning a tree of shapes	Grain filter.

Structural vs Algebraic Openings

Initial image.

Structural opening with a disk ($r = 15$).

Algebraic opening ($\lambda = \pi r^2$).

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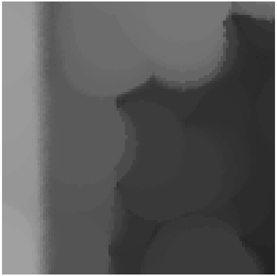

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Algebraic opening ($\lambda = \pi r^2$).

Application: Filtering Everything But Boxes

FIRST

future. According to Dealogic, 87 SPACs have begun trading in the U.S. since the end of 2003, buying some well-known companies like smoothie purveyor Jamba Juice. Last year alone, 40 SPACs worth $3.4 billion were announced, up from $484 million two years earlier.

SPACs are essentially shell companies. They go public with little more to show investors than a management team and an agreement that the money raised will be used to fund an acquisition in a particular sector, such as retail, or in an emerging market like China. Ergo, a SPAC is a roll of the dice. "Imagine paying $50 to go to a Broadway show, and you have no idea what's behind the curtain," says lawyer Mitchell Littman of Littman Krooks LLP, who works with a lot of SPACs. "You are relying on the fortune and integrity of the management team." Once a deal is completed, the SPAC's managers (who typically receive 20% of the public shares as compensation) are free to sell their holdings, usually after a lockup period.

Today's SPAC boom harkens back to the flurry of "blank check" companies that sprang up in the 1980s. Those were widely discredited by a wave of scams in which fraudsters would take a shell company public, announce a merger, pump the stock, and then dump it before everyone realized that the hot target company was anything but. Investors have a lot more protection with SPACs, which must hold almost all the money in escrow until a deal is done.

From Charney's perspective, there is no downside to the arrangement. It lets him raise cash relatively quickly, remain the largest shareholder, and avoid having to sell other investors on his vision until after his company is already publicly traded. "I'm in a hurry to get the money," he says, citing his plan to expand beyond his current 145 stores. "What's great about the SPAC is, it's kind of in reverse. First you get publicly traded, then you do the compliance stuff. And if you brought in private equity, they might want to run the company in a more [cautious] manner," he says, referring to American Apparel's risqué image.

FIRST YOU GET PUBLICLY TRADED, THEN YOU DO COMPLIANCE.

Keeping control is particularly important for a guy who is the creative force behind the brand, as well as one whose flamboyant management style—there is one sexual-harassment suit outstanding against him by a former employee; two others have been dismissed—might scare off many investors. "He is very talented," says former J.C. Penney CEO Allen Questrom, a partner in private-equity firm Lee Equity Partners, "but he is a *meshugana* [read: nutty] type guy. It's very difficult to see him in a public sphere." (Charney, for his part, dismisses the talk about his reputation as "all tabloid.")

Charney's new bedfellows don't appear concerned, even if they're more likely to wear dark suits than American Apparel's colorful leggings. Endeavor's president, Jonathan Ledecky, is familiar with unusual financing vehicles; he founded U.S. Office Products, the once-hot roll-up that went bankrupt in 2001 (long after Ledecky cashed out). Boldfaced names on the board include Kerry Kennedy, Bobby's daughter, and Edward Mathias, a managing director at the Carlyle Group. On Jan. 31 the same group formed a new $250 million SPAC, Victory Acquisition, underwritten by Citi. The filing notes that it could compete directly with Endeavor. And as with Endeavor, once Victory goes public it will pay a Ledecky "affiliate" $7,500 monthly to run its Manhattan office.

Hedge funds are drawn to these investments. Since SPACs typically must announce a deal within 18 months of their IPOs or return the money raised, with interest, hedgies see them as safe places to park cash while potentially profiting from the price fluctuations between a deal's announcement and its close—a sort of arbitrage play. That may be why Steven Cohen's $12 billion hedge fund SAC Capital snapped up 8.7% of Endeavor's stock when the deal was announced.

Even if investors are SPAC-happy, not all regulators are: So far only the American Stock Exchange lists SPACs, and many bankers and lawyers say the SEC is deliberately taking its time vetting deals, hoping to slow down the pace of offerings. SPACs are probably best left to those, like Charney, who like to live life on the edge.

SPAC Attack!

The volume of special purpose acquisition companies going public in the U.S. is rising sharply.

Number of deals
Value of deals (in billions)

2004: 13, $0.5
'05: 29, $2.1
'06: 40, $3.4

UNHEALTHY RETURN Since smoothie chain Jamba Juice went public in November via a SPAC, its shares have fallen 19%.

FORTUNE CHART / SOURCE: DEALOGIC. PHOTO: DAVID MCNEW—GETTY

12 • FORTUNE February 19, 2007

Application: Showing Filtered Lines

AFRICA

Emotional Intelligence

Soul City, South Africa's wildly popular soap opera, spreads public-health messages across the continent

By PETER HAWTHORNE JOHANNESBURG

IT'S 8:30 ON A TUESDAY NIGHT, AND MILlions of South Africans are tuning in to find out if the white social worker, Karen, will be able to adopt AIDS orphan Benni—"People who love me always end up dying," the child says. No, it's not *Melrose Place* or *E.R.* or any of the other imported dramatic series that fill the country's airwaves. It's a show about South Africans themselves. *Soul City*, the local soap opera that began as a good deed, is now an award-winning, multi-media business internationally recognized for its role in Third World development. It is also one of the top three most widely watched progams on South African TV.

IT'S A WRAP: Actors on the set take a breather from filming after a successful take

HIGH DRAMA: Confronting prejudices toward HIV is one of Soul City's main objectives

EDUCATIONAL FOCUS: Benni tries his hand learning sign language at the township clinic

Soul City reflects the life and hard times of people in a typical South African urban black township. In fact, most of the series' location shots are taken in Alexandra, one of the oldest and most squalid of South Africa's black slums, just outside Johannesburg. And *Soul City's* clinic, where much of the drama is centered, is based on an actual clinic in Alexandra.

That medical theme is not surprising, since the idea for the show came from two young white South African doctors, Garth Japhet and Shereen Usdin, who had studied and worked in township hospitals and clinics, including in Alexandra. They envisioned a dramatic program that would highlight the social and health problems—particularly HIV-AIDS—in the townships. They convinced a long list of donors—which today include the European Union, Britain's Department for International Development, UNICEF, British Petroleum, the mobile-phone network MTN and the South African government's Department of Health—to put up the money, and *Soul City* was launched nationwide on the South African Broadcasting Corporation's TV service in 1994. "We realized that to be effective we had to go out at prime time, we had to keep it going and we had to be as good as or even better than any other production," says Japhet. Since then, *Soul City* has collected a bundle of prizes. On June 14, the show received a special award from Britain's One World Broadcasting Trust for its role in "illuminating the concerns of developing societies."

Because AIDS is a huge problem in South Africa—almost 10% of the population is infected with HIV—the subject is featured in every installment of the show. Other topics include violence against women, drunkenness, rape, child abuse, sexual conduct, occupational health, disability, setting up a business, even buying and selling a used car. "This is not just about reality in life, it's about real-life skills," says Japhet, who is executive director of the nongovernmental Institute for Health and Development Communications, which produces the show. *Soul City* also has a radio version broadcast daily in nine of South Africa's 11 official languages, as well as weekly newspaper columns and a series of educational booklets.

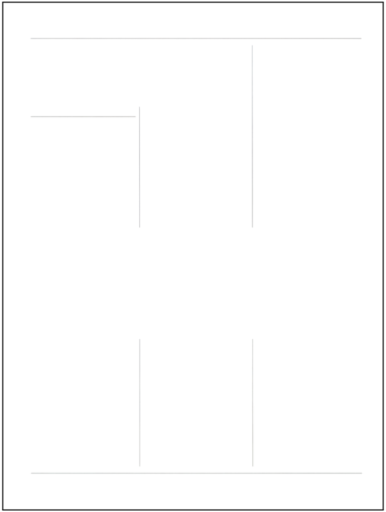
Characters speak in several of South Africa's official languages, and the series is subtitled in English. It has been shown in Zimbabwe, Zambia, Nigeria, Namibia, Malawi and Barbados and has been dubbed into French and Portuguese for showing in Ivory Coast, Mozambique and other countries. "This concept has got legs," says Japhet. "It moves."

It has also spun off *Soul Buddyz*, a show for younger viewers, which began a 26-episode run on SABC-TV last year. Much as *Soul City* does for adults, *Soul Buddyz* looks at AIDS and other problems as they affect the young. The show is already being sought by countries outside South Africa.

What makes *Soul City* so successful is not merely its authentic portrayal of township life but also its intimacy with viewers. Many of the actors live in the townships. "That sometimes presents a problem," says Lebo Ramafoko, producer of the latest series. "Our actors are seen as real people. They have to become the advocates and counselors they portray on the screen." Some of the cast members have been discovered through *Soul City's* annual "Search for a Star" initiative. Among them is Doreen Kotsedi-Pitse, a blind woman who will play the part of a radio talk-show coordinator. Kotsedi-Pitse lost her sight as a result of domestic violence, an issue frequently raised by *Soul City*. "It made us all aware how uncomfortably close we are to real life," says Ramafoko.

Soul City is affecting the way South Africans lead their real lives. A study sponsored by the E.U. says there is evidence that the program has played "a major role" in increasing public knowledge of HIV-AIDS and safer sexual behavior. Researchers say, for instance, that there is a "significant" association of the use of condoms with people who watch *Soul City*. The survey did not say whether Benni would find a happy new home. For more about that, tune in to next week's episode. ■

38 TIME, JULY 2, 2001



Application: An Image Featuring Almost Only Text

Briefing

Verbatim

'Nobody is going to be allowed to do anything here.'

WAHEED ARSHAD, Pakistani Major General, on reports that the U.S. may expand military and CIA authority to pursue Islamic militants in Pakistan

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PHILIP S. BARIE, chief of the division of critical care at New York–Presbyterian Hospital, on the recuperation of Alcides Moreno, a 37-year-old window washer who fell 47 stories last month

'We should not resort to violence even if we have differences.'

MAUMOON GAYOOM, President of the Maldives, after an attempt to assassinate him was foiled when a boy scout waiting to greet the island nation's leader grabbed the attacker's knife as he lunged out of a crowd

'This is who I am. This is my life.'

SERGEANT DARREN MANZELLA, U.S. Army medic and a decorated veteran of Iraq, discussing his homosexuality in a Jan. 8 press conference. Manzella has been openly gay since August 2006, despite the military's "Don't ask, don't tell" policy; its critics have argued that his case proves the policy is arbitrarily enforced

'They should either kill me or organize a second round of elections.'

LEVAN GACHECHILADZE, Georgian opposition leader, after his resounding defeat by pro-Western incumbent Mikhail Saakashvili in the country's Jan. 5 Presidential elections. Gachechiladze claimed the voting was rigged

'This is the first red carpet that I've really walked down where I didn't have to think about holding in my stomach.'

HALLE BERRY, on being pregnant, while accepting the Desert Palm Achievement Award at the Palm Springs International Film Festival on Jan. 5

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Sources: A.P.; New York Times; A.P. (2); BBC; PEOPLE

NUMBERS

CENSORSHIP

16,600%
Percentage by which Burmese authorities have increased the license fee to receive satellite TV, the country's only broadcast-news source not controlled by the state

300%
Percentage by which the new fee—about $800—surpasses the annual salary of a Burmese schoolteacher. The increase is seen as a move to block access to news critical of the ruling military junta

HEALTH

65%
Percentage of U.S. adults who are exercising, dieting or both during any nonholiday period

29
Number of pounds (13 kg) that at least 25% of American adults currently on a diet would like to lose. Regular exercisers said they want to drop an average of 14 lbs. (6.3 kg)

GOLD

$884
Record price per ounce of gold set on Jan. 8, as investors reacted to market turbulence and high oil prices, beating the previous all-time record of $875 set in 1980

$2,200
1980's record price for gold, when adjusted for inflation

WEALTH

$46,380
The U.K.'s per capita gross domestic product this year, $500 more than U.S. per capita GDP. For the first time since the 19th century, the average Briton will earn more than the average American

1993
The year following Britain's last major recession, when the country's per capita GDP was 34% less than that of the U.S.

Sources: Reuters; A.P.; Pew Research Center (2); International Herald Tribune; A.P.; BBC (2)

LEFT COLUMN, FROM TOP: OLIVIER MATTHYS—EPA/CORBIS; LAKRUWAN WANNIARACHCHI—AFP/GETTY IMAGES; JAY JANNER—WPN; MATT SAYLES—AP; RIGHT COLUMN: TORU HANAI—REUTERS

12 TIME January 21, 2008

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Connected Filters: Conclusion

- Benefits
  - Non destructive (preserve contours).
  - Sound and strong mathematical properties [Soille, 2004, Najman and Talbot, 2010].
  - Take into account all components.
  - Really intuitive to use.
  - Very extensible (many attributes).
  - Efficient.
- Applications in Document Image Analysis.
  - Page segmentation.
  - Text identification.
  - Object recognition.
  - “Smart” binarization.
  - Etc.

Implementation: The Olena Platform

Code and tools available in Olena, a free software image processing platform.

`http://olena.lrde.epita.fr`

Milena

A generic and efficient C++ image processing library [Levillain et al., 2010].

Scribo

A framework for Document Image Analysis [Lazzara et al., 2011].

Thank You!

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