The Language of Mines: Motivation to Remediation

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Languages of Mines

Military motivation for landmines

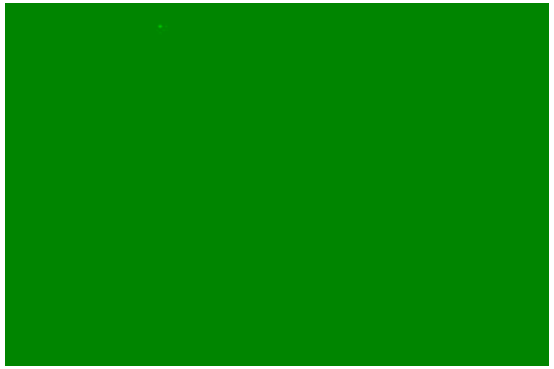
Political desire to limit landmines

Humanitarian need to ban landmines

Engineering ability to remediate landmines

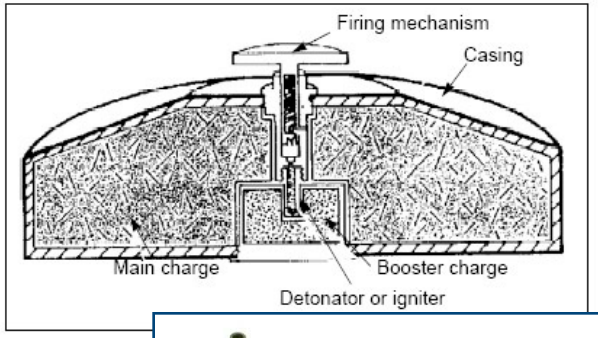
A Brief History of Modern Landmines

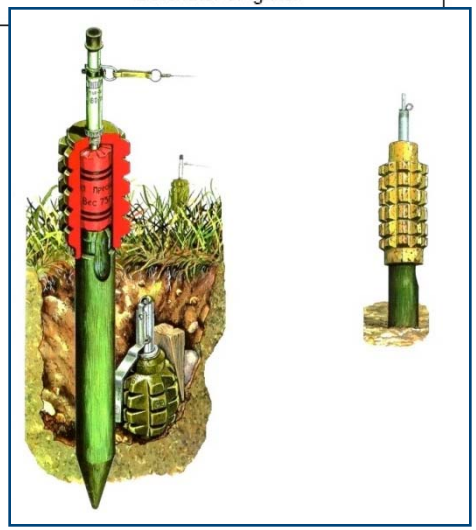
- Yorktown, VA, 1862, Wm. T. Sherman, *Memoirs*[1]
  - "There had been no resistance at that point, nothing to give warning of danger, and the rebels had planted eight-inch shells in the road, with friction-matches to explode them by being trodden on. This was not war, but murder, and it made me very angry. I immediately ordered a lot of rebel prisoners to be brought from the provost -guard, armed with picks and spades, and made them march in close order along the road, so as to explode their own torpedoes, or to discover and dig them up. "
- Somme, France, 1916: British Mark I tanks were introduced as a counter to the stalemate of machine guns and trench warfare

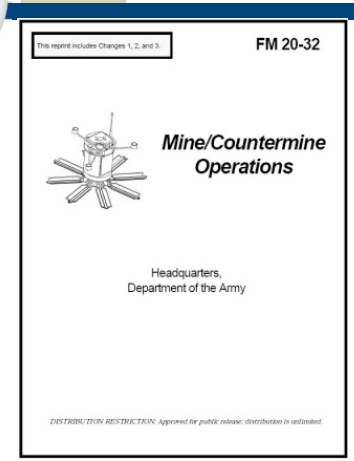


From Anti-tank to Anti-personnel

- Anti-tank (AT) landmines were developed during WW-I as a response to tanks
  - IEDs: In response to the introduction of the tank by the British, Germans improvised mines from artillery shells
  - Purpose built: Germans produced Flachmine 17 comprised of wooden box with with springs and explosives
  - Soldiers would dig up AT landmines and move them to their own defensive minefields
- As of 1999, there were at least 350 mine types, manufactured in 50 countries[2]

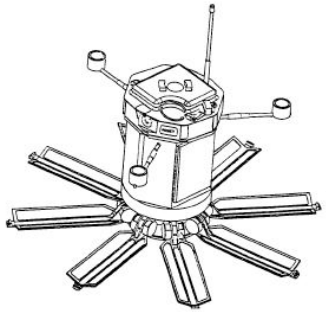




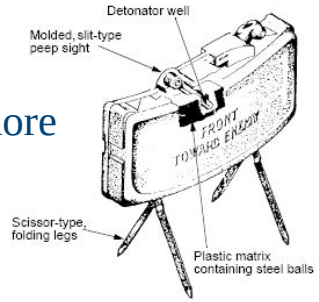


Military Landmine Terminology[3]

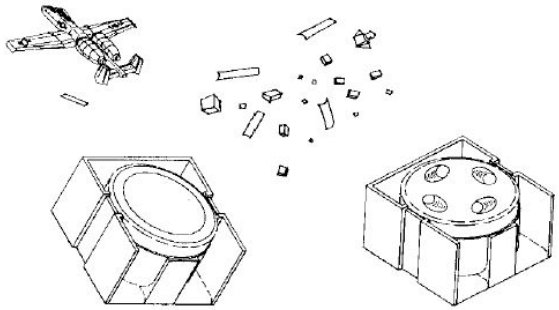
- **Antitank mines (AT)**: AT mines are designed to immobilize or destroy vehicles and their occupants
- **Antipersonnel mines (AP)**: AP mines can kill or incapacitate their victims
- **Antihandling devices (AHD)**: AHDs perform the function of a mine fuse if someone attempts to tamper with the mine
- **Scatterable mines (SCATMINE, Cluster munitions, FASCAM)**: Laid without regard to a classical pattern. They are designed to be delivered or dispensed remotely by aircraft, artillery, missile, or a ground dispenser



M-93 Hornet Wide Area AT Mine



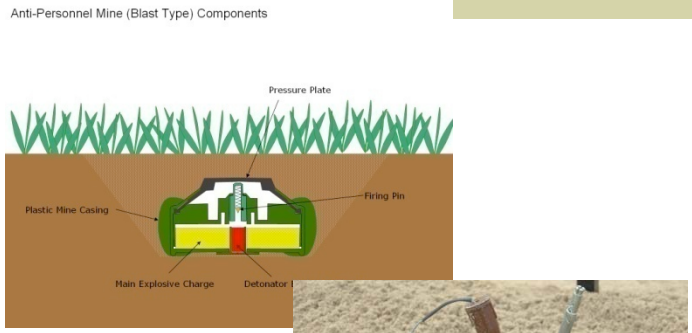
M-18A1 Claymore AP Mine

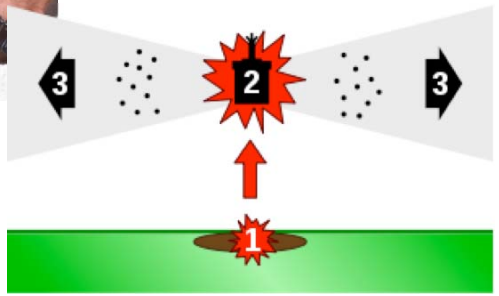


GATOR AT/AP SCATMINE

Anti-Personnel Landmines

- Anti-personnel (AP) landmines were developed and placed in AT minefields to prevent soldiers from “regifting” AT landmines
- To inhibit enemy troops from clearing antitank minefields, small metal or glass containers with a small amount of explosive and a contact or tripwire detonator were scattered about as primitive AP mines.





Army Motivation for Use of Landmines

Minefields[3] are used by the military to:

- Inflict damage to enemy personnel and equipment
- Delay enemy forces in order to exploit the capabilities of other weapon systems
- Cause an adversary to move in a less advantageous direction
- Cause the enemy to piecemeal his forces; divide and conquer
- Interfere with enemy command and control (C^2)
- Protect friendly forces from enemy maneuver and infiltration

Cost Effectiveness of Landmine Usage

- Landmines are cheap to manufacture (F-22 $132M, landmines $3-$30)
- Landmines do not require maintenance
- Static obstacles (ditches, moats, barbed wire) are more costly to implement and require continual maintenance and are not mobile
- Dynamic obstacles (artillery, bombs) require continuous outlay of armaments and their use may be weather dependent
- Landmines can be made “smart”
  - Self-detonating
  - Self-deactivating
- Landmines channel adversaries into “killing zones” which increases effectiveness of other weapons

Military Motivation for AP Landmines not Universally Supported by Opinion or Analysis[4]

- The US Army had no studies demonstrating the military utility of landmines as of 1994…"
- "As General Joseph Ralston, vice-chairman of the Joint Chiefs of Staff, summed them up on May 16, 1996, "The historical record is mixed concerning antipersonnel landmines. We know that they cause casualties, some enemy and some friendly."
- According to an IDA study, antipersonnel mines are of substantially more restricted utility than antitank mines.

Korea and Iraq

- The major US justification for landmines seems to be the DMZ between North and South Korea[4]
  - The ROK Army has
    - 2 million mines in its own stockpiles.
    - 685,000 mines in US stocks earmarked for its use.
  - The US is replacing its dumb mines with self-deactivating mines
- US took no "dumb" mines to the Persian Gulf[5]
  - US forces transported over 2.2 million landmines, antipersonnel and antitank, self-destructing and not, to the Persian Gulf, but used just under 118,000, all of them smart mines.

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Ottawa Convention[6] Vocabulary

- **Mine** means a munition designed to be placed under, on or near the ground or other surface area and to be exploded by the presence, proximity or contact of a person or a vehicle. (treaty)
- **Anti-personnel mine (AP)** means a mine designed to be exploded by the presence, proximity or contact of a person and that will incapacitate, injure or kill one or more persons. (treaty)
- **Anti-handling device (AHD)** means a device intended to protect a mine and which is part of, linked to, attached to or placed under the mine and which activates when an attempt is made to tamper with or otherwise intentionally disturb the mine.

Political Vocabulary

- **Moratorium**: stop, for a limited time, the export or transfer of landmines
- **Ban**: abolish the production and use of landmines
- **Primarily**: used with reference to AT mines which have AHD capabilities
- **"Dumb" or persistent mines**: those which remain active until detonated or cleared[7]; not self-deactivating or self-destructing

Economics of Landmine Production[4]

- Landmine production is ubiquitous: 41 firms and government agencies in 29 countries
- Russia, China, and Italy export the most
  - "Italy was a leading exporter, selling 200,000 landmines to Saudi Arabia and Egypt in 1992. Italian-made mines had turned up in Afghanistan, Angola, Cambodia, El Salvador, Mozambique, Nicaragua, Somalia, and Yugoslavia."
- "[since]…the global market in landmines was estimated at less than $100 million a year, a fraction of the $20 billion a year spent on arms-US arms manufacturers were not inclined to counter the ban."
- "As dreadful a human toll as landmines exact, their economic impact may cause even more harm. They force fertile fields to lie fallow, restrict livestock from watering holes or feeding grounds, and impede goods from reaching markets …"
- "A study by the Institute for Defense Analyses also suggested the limits of arms control. Because landmines were so inexpensive to produce and use, it reasoned, arms control agreements would have to impose "significant" costs for evasion and concealment…to effect a large reduction of landmine use."

Effective Political Language

- Rather than regulate landmines, there was a small group of non-governmental organizations (NGO) and countries other than the US who thought the best way to counter political double speak was to just get rid of them--ban them altogether like poison gas after World War I or other WMD.
  - Approach: stigmatize landmines as being against moral norms
  - Eradication rather than control became the issue
- In October 1992 the International Campaign to Ban Landmines (ICBL) was founded
  - It found support in the US in the form of Senator Patrick Leahy
- Days after the founding of ICBL, President G. H. W. Bush signed the Leahy moratorium into law

Diplomatic Approach to Banning Landmines[4]

The diplomacy that emerged from these sessions had four key political premises.

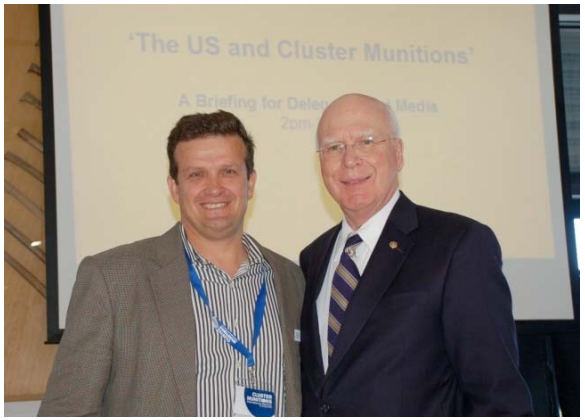
1. What would become the Ottawa process was a gathering of the like-minded in a stand-alone forum. That meant countries had to opt in or opt out. By implication, a ban could emerge with or without Washington's participation …
2. Non-governmental organizations (NGO) were finally on the inside
3. NGOs were not just present and participating, but were also influential in shaping policy and instrumental in attracting media attention to the ban and shaming governments into action
4. Diplomats adopted the campaigners' way of framing the issue in moral terms, as a matter of basic human rights

Fighting the Moral Political War[4]

- "By framing the issue in human rights terms, the NGOs sought to cast a moral stigma on landmines and shame governments into banning them. "
- The spearheads of the landmines ban in US Congress were Senator Leahy (D -VT) and Representative Evans (D-IL)
- Having secured a 3-year moratorium on exports in 1993, Senator Leahy moved to extend the moratorium to US production of antipersonnel landmines in 1994.
- "On September 26, 1994, the ban campaigners won backing from yet another unexpected source. In an address to the UN General Assembly, President Clinton endorsed the "ultimate goal of the eventual elimination of antipersonnel landmines." As if 'ultimate' and 'eventual' did not make that goal provisional enough, he added yet another proviso, 'as viable and humane alternatives are developed.' "

US Anti-Landmine Advocate, Vermont Senator Patrick Leahy[8]

- 1989: Sen. Leahy established War Victims Fund
- 1992: Leahy wrote the first law enacted by any government to prohibit the export of these weapons. He worked in Congress to develop programs to assist mine victims, including establishing a special fund in the foreign aid budget. The bill was signed into law by Pres. Bush
- 1993: Amendment to law extended moratorium to 3 years, signed into law by Pres. Clinton
- 1996: Introduced UN resolution proposing "vigorous" negotiation to ban landmines



Prof. Ken Rutherford (SW Missouri State) , Sen. Leahy

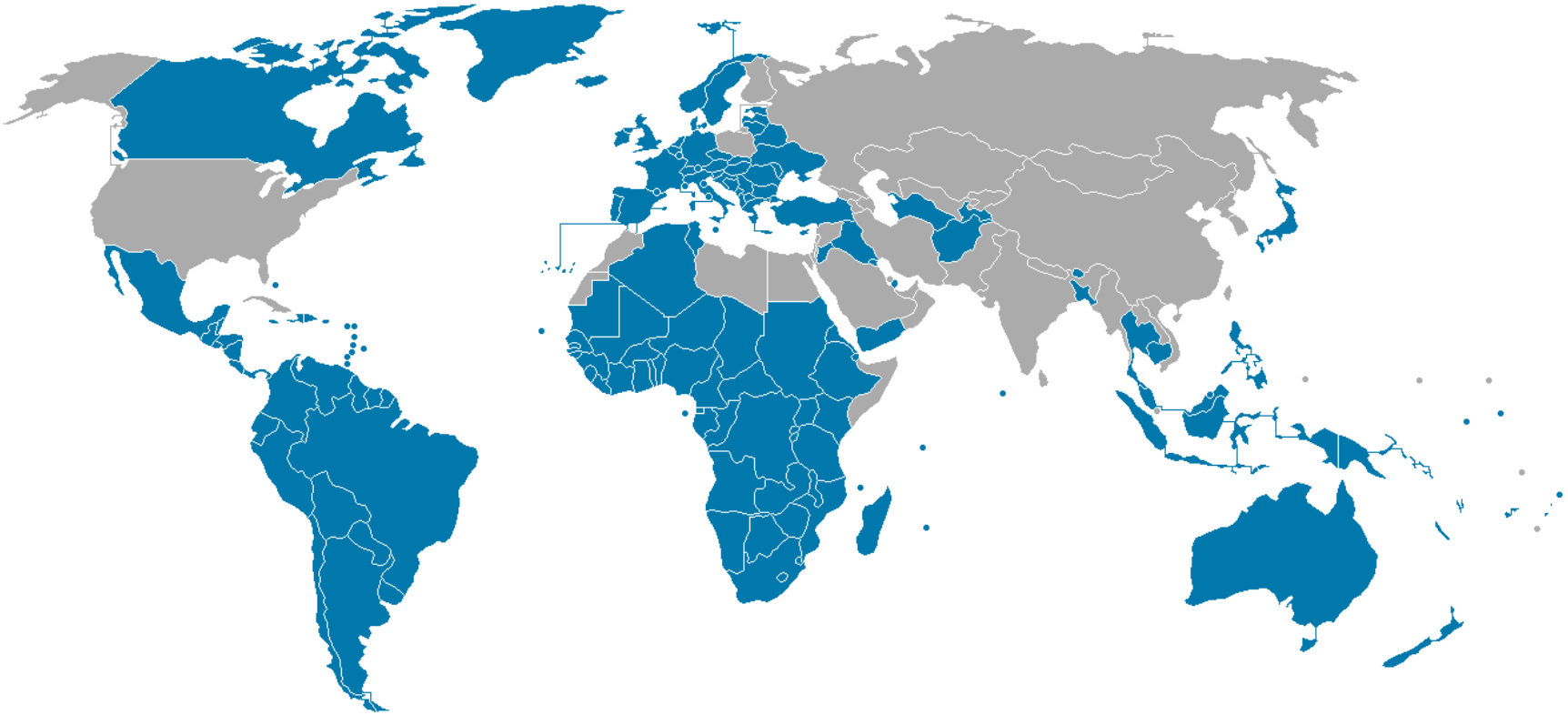
Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction[6]

- Unofficially, the 1997 Ottawa Convention/Accord/Treaty
- Canada was instrumental in winning acceptance for the treaty which resulted when representatives from 122 sovereign nations gathered in Ottawa, Canada, in 1997
- The United States did not sign the ban at that time and has not yet signed it
- 1994: Pres. Clinton declared to the UN the goal of the US which was the eventual elimination of AP landmines

US Position on AP Ban

- May 16, 1996 [7]: President Clinton announced that
  - "Until an international ban takes effect, the United States will reserve the right to use so-called smart mines or self-destructing mines as necessary.
  - But under the comprehensive international ban we seek, use of even these smart anti-personnel mines would also be ended."
- February 27, 2004 State Dept policy[9] (in part)
  - Eliminate all persistent landmines from its arsenal;
  - Seek a worldwide ban on the sale or export of all persistent landmines;
  - Not use any persistent landmines -- neither anti-personnel nor anti-vehicle -- anywhere after 2010
- When is an AP mine not an AP mine
  - US Position: When its "primary" use is anti-vehicle
  - "…US forces are not authorized to employ AHDs on any type of AP mine." [3]

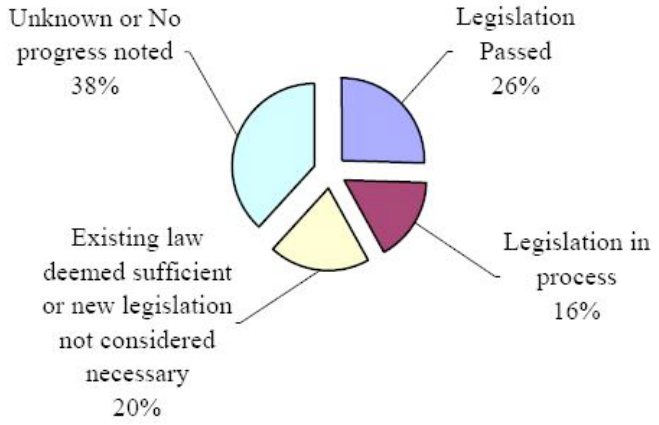
Ottawa Accord: 156 Signatories, 39 Not



Not signed as of December, 2008 [10]: US, PRC, India, Pakistan, Russia, Cuba, Egypt, Finland, Israel, Korea (N&S), Myanmar, Saudi Arabia, Vietnam, *+24 other non-signatories*

Compliance with Ottawa Convention

- ICBL report in 2004 that 60% of signatories have made progress in legislation to ban landmines [11]
- The *Landmine Monitor* now estimates that 54 countries have stockpiles, totaling 180 million anti-personnel mines. [12]
- There are 13 countries that continue to produce anti-personnel landmines: Myanmar, China, Cuba, India, Iran, North Korea, South Korea, Nepal, Pakistan, Russia, Singapore, United States, and Vietnam Vietnam.[12]



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Humanitarian *vs.* Military POV

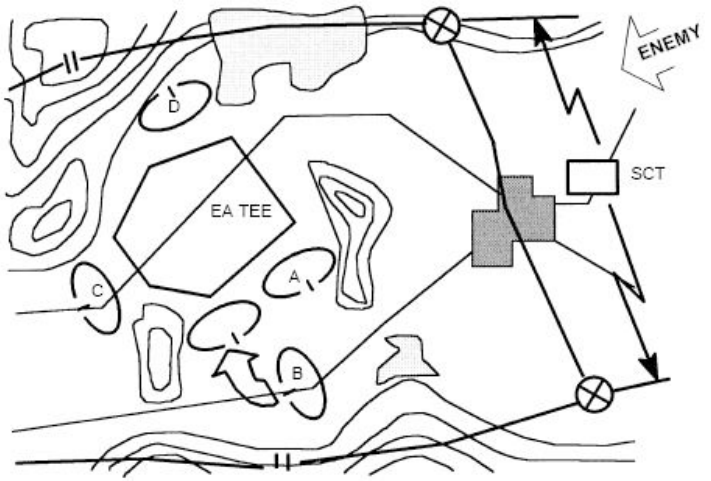
- The Law of Land Warfare [3]:
  - "…desire to diminish the evils of war by …protecting both combatants and noncombatants from unnecessary suffering …"
  - "…requires that belligerents refrain from employing any kind or degree of violence which is not actually necessary for military purposes and that they conduct hostilities with regard for the principles of humanity and chivalry."
- Secondary effects of landmines are of benefit to military campaigns
  - "Often designed to maim, their psychological impact on the enemy is undeniable…. landmine casualties can also overload military logistical support systems since most mine victims require more extensive medical …attention." [13]
- "What sets the weapon apart is its time-delay function. Not designed for immediate effect, landmines lie dormant until triggered by a victim." [13]

Landmines in Humanitarian Terms

- Humanitarian needs lead to a desire to ban, not simply "manage" both AT and AP landmines
- Victim Assistance [14] is a major unfunded problem
  - Pre-hospital care
  - Hospital care
  - Rehabilitation
  - Social and economic reintegration
  - Disability policy and practice (public awareness)
  - Health and social welfare surveillance and research

Lingering Effects of Insurgents, Paramilitary, and the Weather [2]

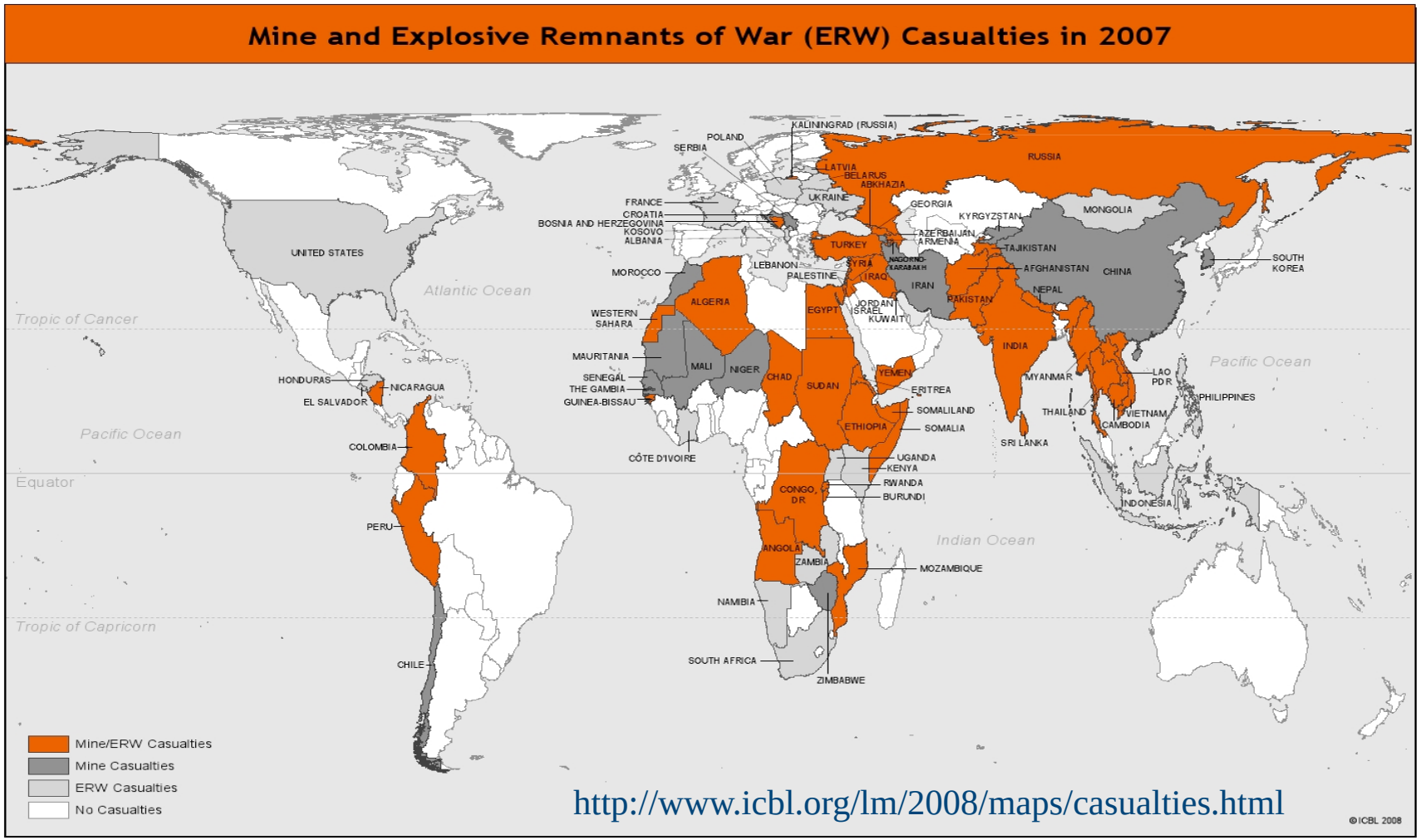
- Few if any records are kept of minefields by non-governmental forces
  - "For example, in Mozambique, a town of 10,000 was deserted for four years because of a rumor that mines were present; a three-month clearance operation later found only four mines."
  - "Andersson et al. (1995) estimated that without mines, agricultural land use in Afghanistan could increase by 88-200 percent."
- Meteorological forces such as rain, wind, and frost heave cause landmines to be exposed, hidden, dislodged, moved, and overturned
  - Even known minefields "move"



Outlook for Mine-Free World is not Improving [2]

- Mine emplacement rate exceeds mine remediation rate
  - Landmines claim an estimated 15,000-20,000 victims per year in 90 countries
  - The U.S. State Department estimates that a total of 45-50 million mines remain to be cleared
  - Worldwide, an estimated 100,000 mines are found and destroyed per year. At that rate, clearing all 45-50 million mines will require 450-500 years, assuming no new mines are laid. By some estimates, roughly 1.9 million new mines are emplaced annually, yielding an additional 19 years of mine clearance work every year.
- Cost of humanitarian demining rising
  - The United Nations has estimated that the average cost of clearing a mine is $300-1,000 per mine.
  - Based on this average, the cost to clear all 45-50 million mines worldwide will total $14-50 billion.

2007 Casualties Span the Globe



Worldwide Legacy of Conflicts

- "Released in August 1983, that study estimated that 85 to 90 million mines lay scattered in 62 countries. Mines killed or injured roughly 150 people a week, most of them civilians." [4]
- "The number still sticks in my mind that 1 out of every 236 Cambodians was a landmine victim…" [4]
- As of 2005, more than 200,000 square kilometers (combined area of Virginia, Maryland, and W. Virginia) are suspected to be contaminated by landmines and unexploded ordnance (UXO).[12]

Hazards of Demining

- The typical deminer's tool kit today largely resembles those used more than 50 years ago. It consists of a metal detector, a prodding instrument (such as a stainless steel probe, pointed stick, or screwdriver), and a tripwire "feeler“ made of a coat hanger or 14-gauge wire. [2]
- The average casualty rate for classical landmine detection is one injured or dead deminer per 1000 mine detection, but rates as high as one injury per100 mines have been encountered [15]

Demining Efforts

- Demining programs in 2006 cleared 140 km^2 of mined areas and 310 km^2 of battle areas (of 200,000 km^2 total mined areas). A significant increase in battle area clearance was recorded over 2005, primarily in Iraq. Afghanistan and Cambodia alone accounted for over 55% of all mined area clearance in 2006. [16]
- Operations resulted in the destruction of 217,000 antipersonnel mines, 18,000 anti-vehicle mines and 2.15 million explosive remnants of war (ERW). [16]
- International Red Cross estimates that it would take 4,300 years to clear the single country of Afghanistan of landmines. [17]

Mine Detection Technologies, Rats to Neutrons

- Ground-penetrating radar (GPR)
- Electrical impedance tomography (EIT)
- Magnetometer
- X-ray backscatter
- Nuclear quadrupole resonance (NQR)
- Neutron interrogation
- Fast neutron analysis (FNA)
- Thermal neutron analysis (TNA)
- Infrared/hyperspectral systems
- Acoustic/seismic
- Biological: Bees, dogs, rats, bacteria
- Chemical
- Innovative prodders and probes

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State of the Art in Electronic Mine Detection [2]

- Conventional metal detectors (magnetometers) have difficulty distinguishing among the metal in landmines and small metallic objects (clutter)
  - High false alarm rate, 100-1,000 inert metal objects for every mine
- Probabilities of detection for military applications lower than humanitarian demining
  - Probabilities of detection varied by detector, location, and soil type. The best performing detector found 91 percent of the test mines in clay soil, but that same detector found only 71 percent of the mines in iron-rich soil.
  - The UN standard for mine clearance is 99.6 percent.

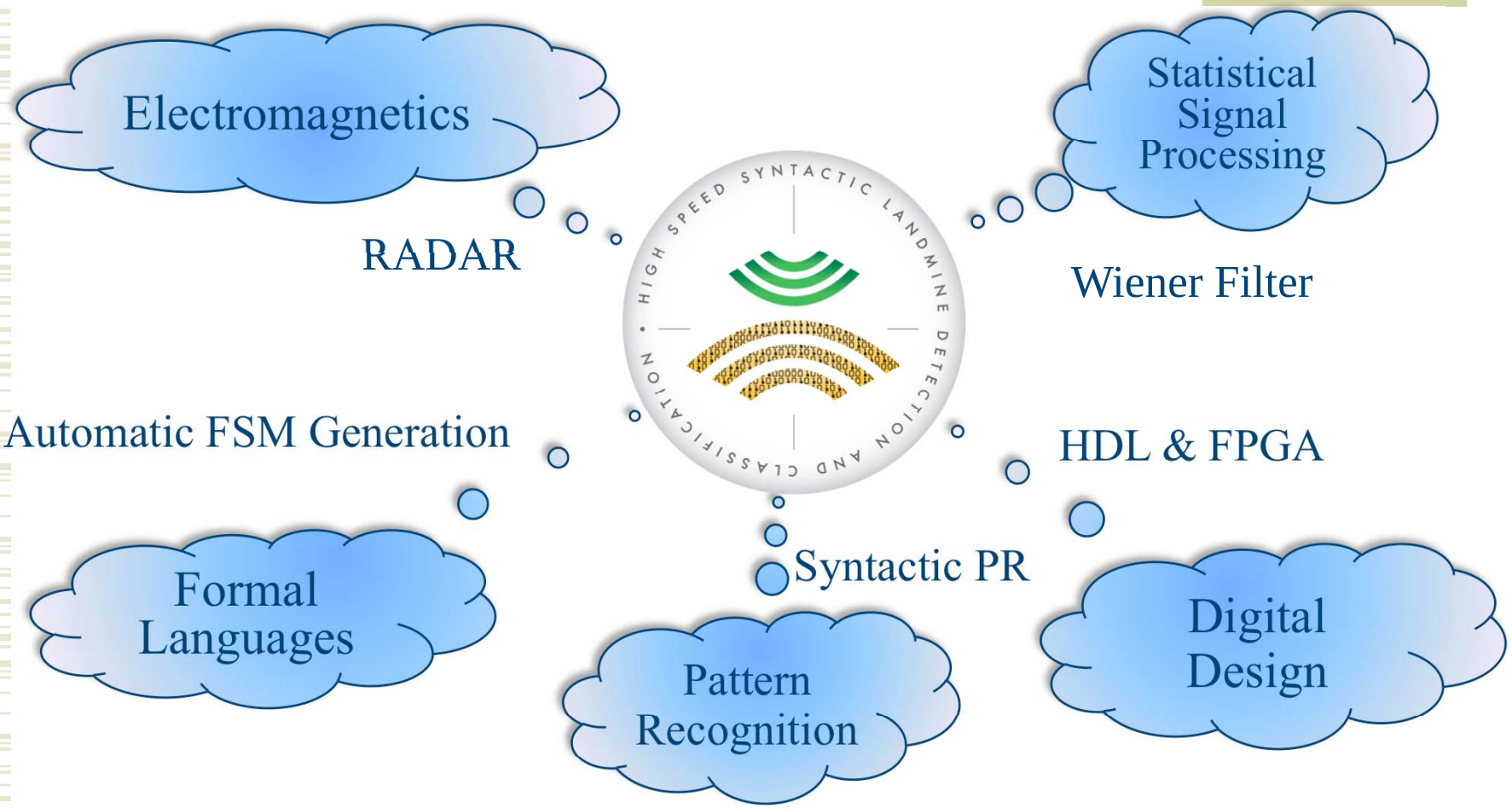
RAND's Assessment of Ground Penetrating Radar [2]

- Ground penetrating radars (GPR) are used for archaeological, forensic, and construction inspection
- Conventional wisdom for GPR
  - Because of fundamental physical limitations of the technologies, no amount of signal processing will eliminate all false alarms from EMI and GPR systems.
- Ideally, GPR systems would be able to provide high-resolution images to a signal-processing system that could decide whether a buried object is a root, rock, clutter object, or landmine.
- Ralston *et al*. suggest development of a "library" of clutter signatures to aid in this task

GPR Problem Is Not Landmine Detection, But Rather Landmine/Clutter Discrimination

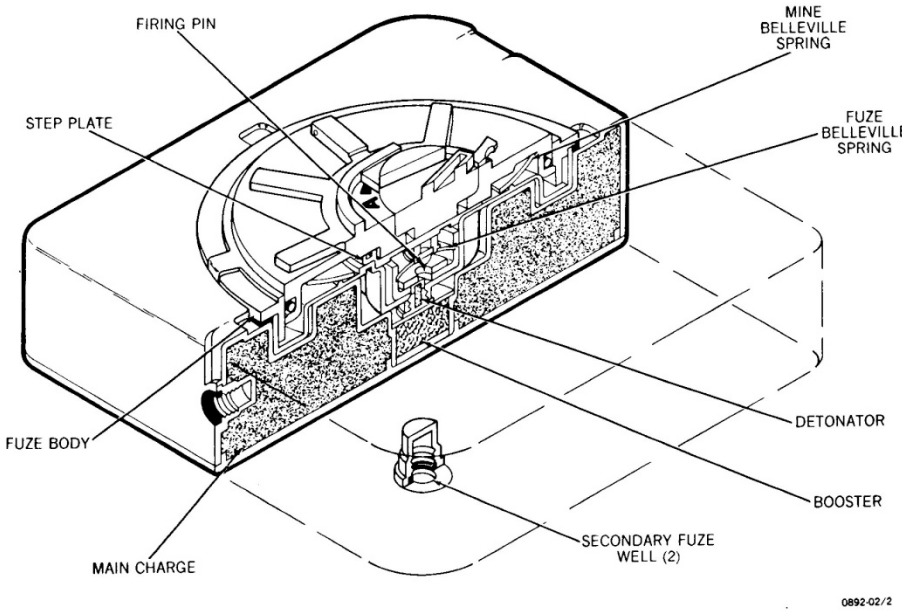
- Engineers usually improve the probability of detection (P_d) of a target by increasing signal to noise ratio (SNR)
  - Doesn't work with clutter, *e.g.*, rocks, roots, hubcaps, holes
- Existing approaches to detection in clutter are typically based on anomaly detection
  - Compute local statistics
  - Set detection threshold to minimize false alarms
  - Effectiveness dependent on the type of clutter and its density
- Matched filtering based on template matching and statistical pattern recognition based on features
  - Ineffective due to large variation of amplitude with aspect angle

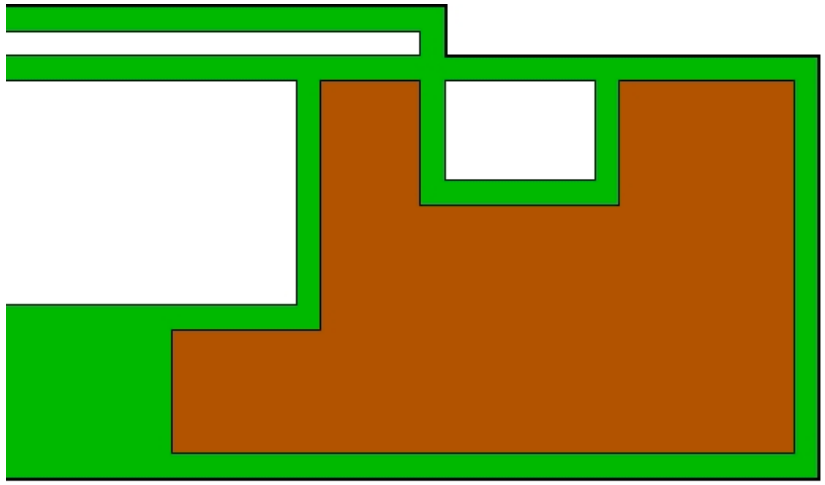
Mason Approach Integrates Diverse and Complementary Technologies



Landmines Have Unique, Repeatable Sequence of Internal RF Reflectors Independent of Soil

Cutaway of US M-19 AT landmine

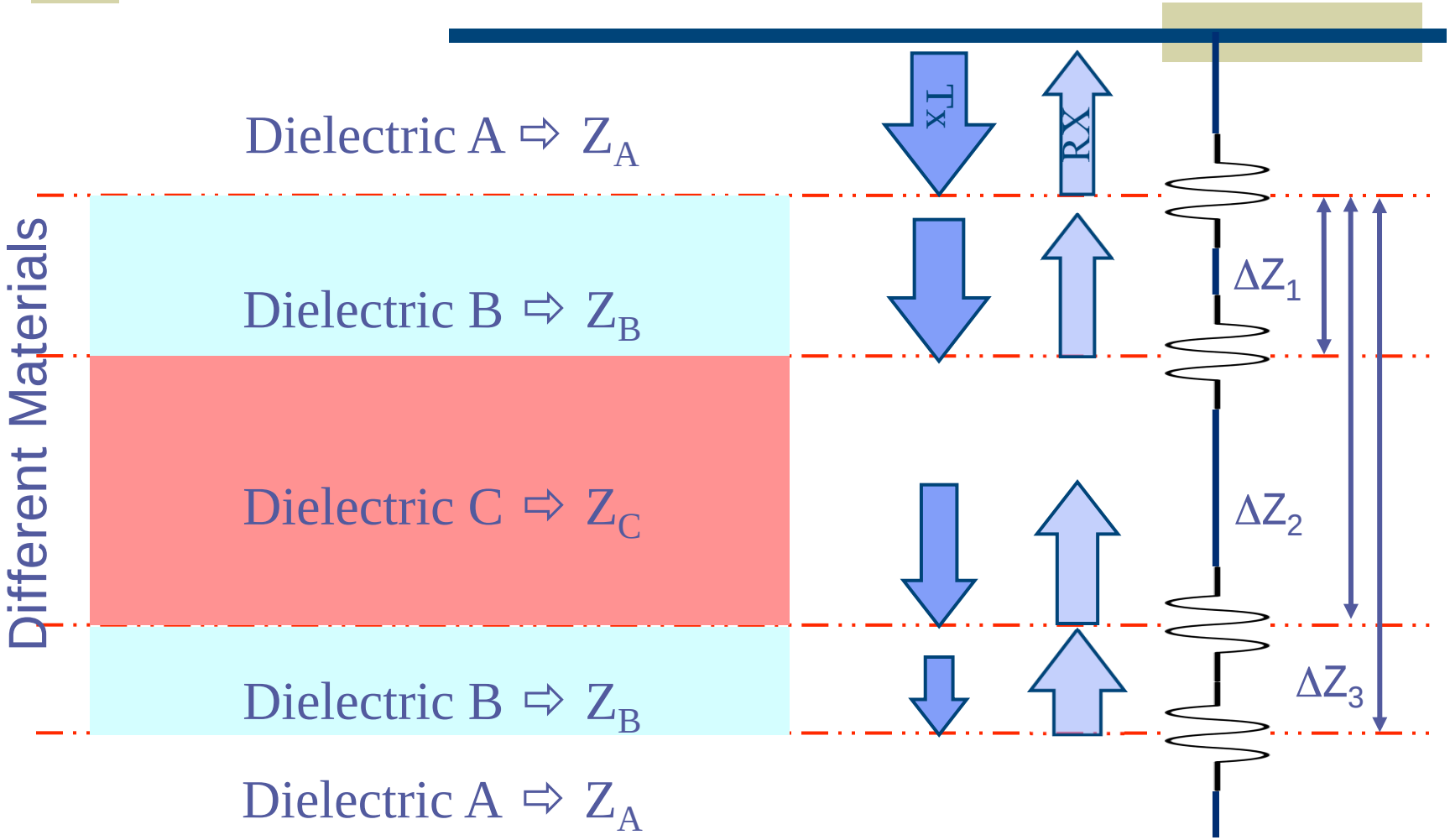




Actual Internal Structure

Simplified model

GPR Senses Reflected Power Due to Changes in Material



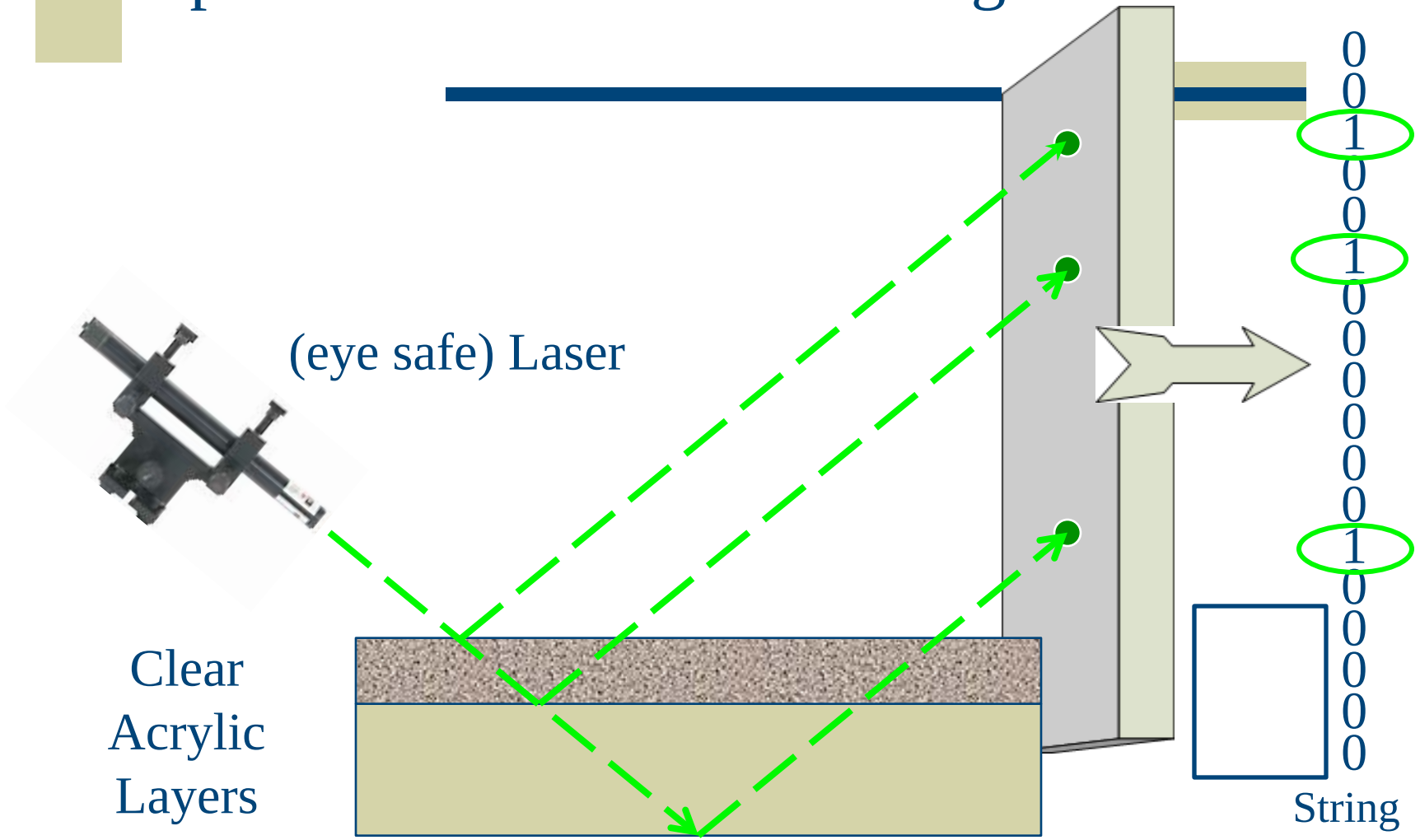
Processing of GPR Signal Makes Landmines Look Similar to UPC Bar Code

In UPC case, laser scanning yields string, *e.g.*,

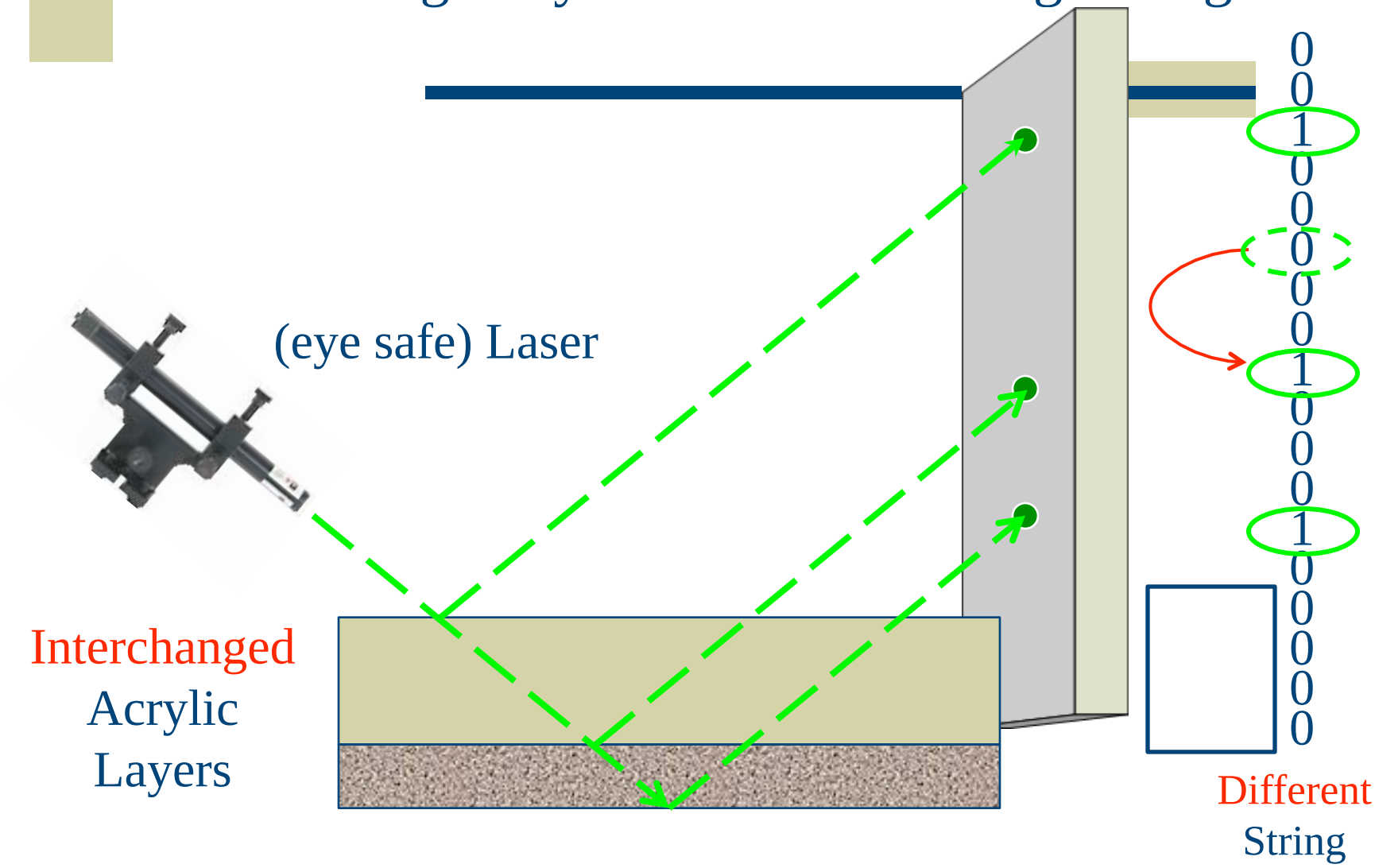
01100011011100001001….

Which is processed to yield decimal number indicating product
36000 29145

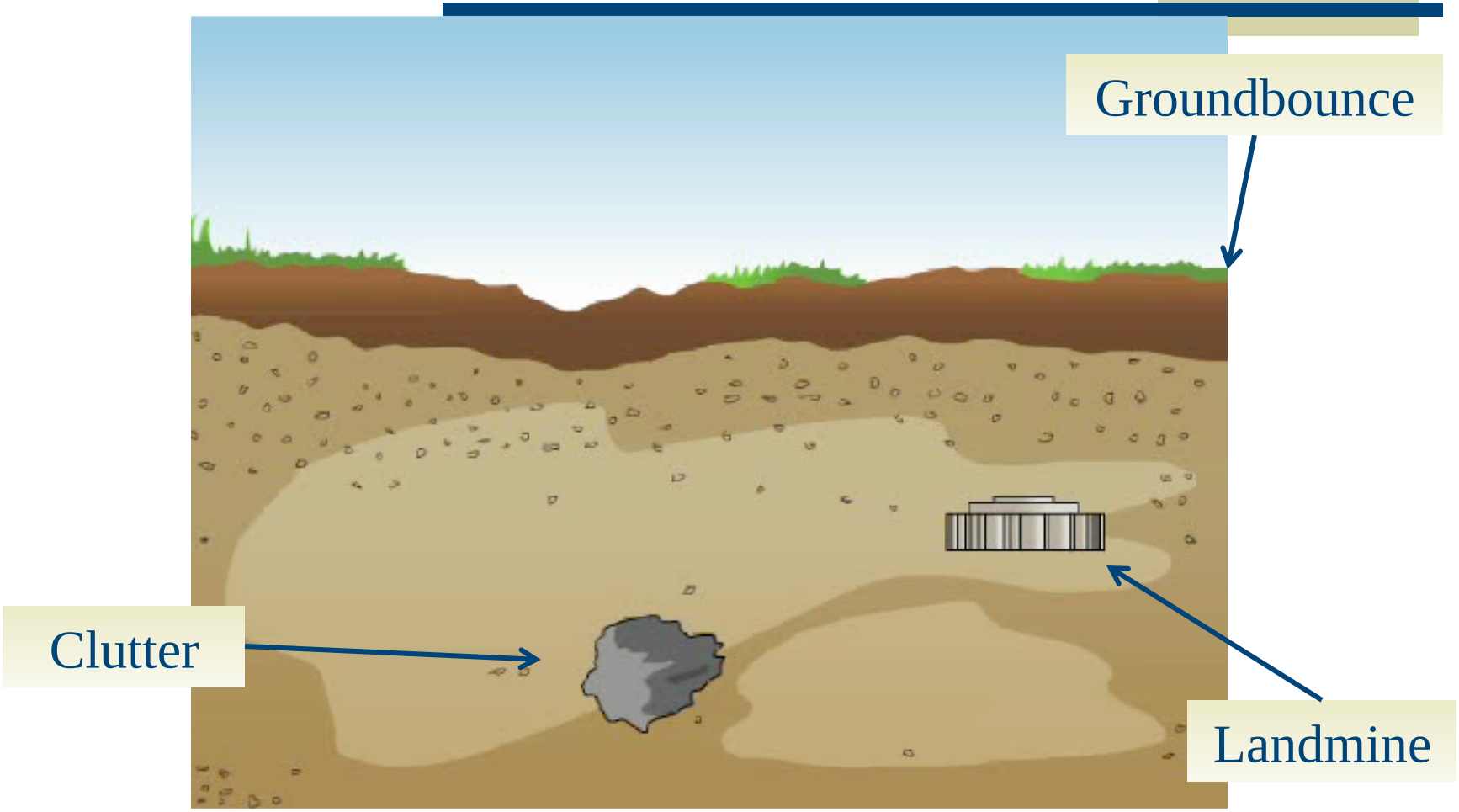
Optical Demonstration Analogous to Radar



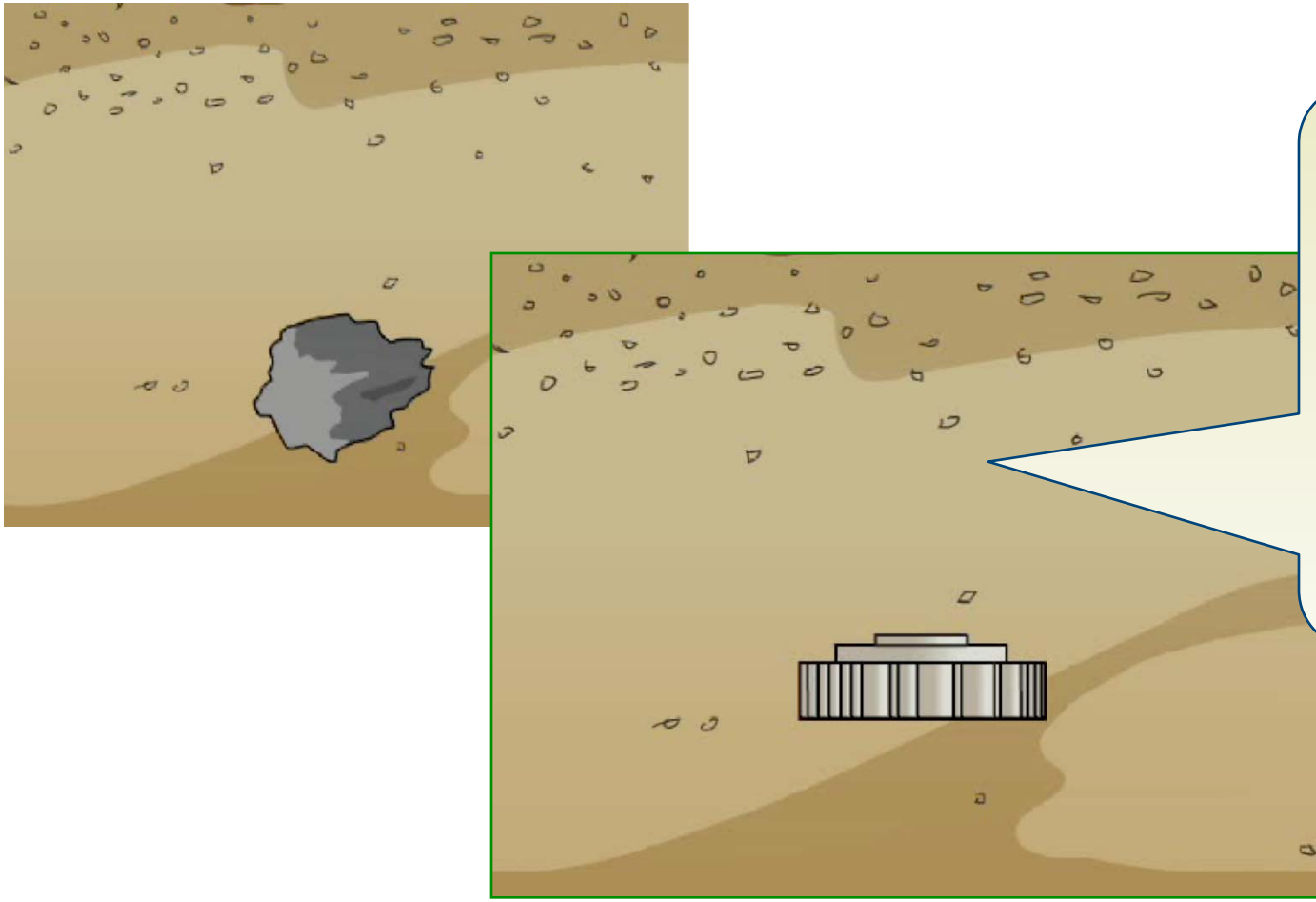
Interchange Layers Results in String Change



Ground Penetrating Radar Sensor

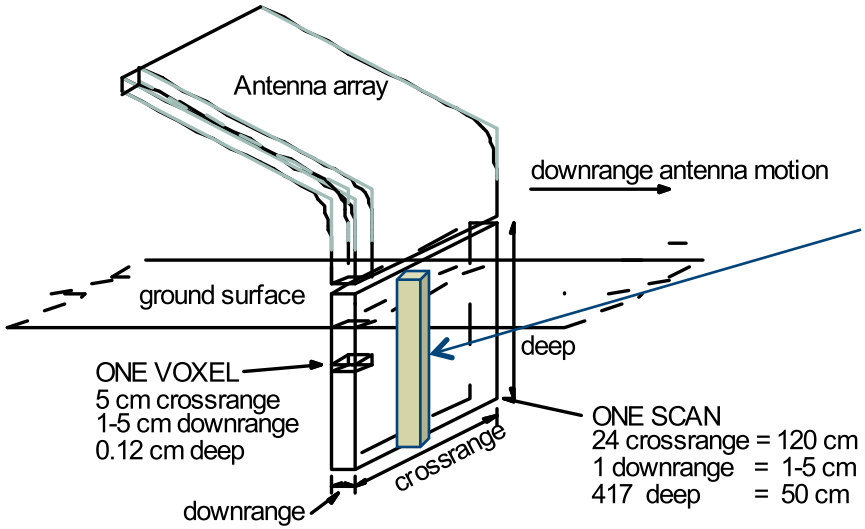


Binarization of Radar Range Return



Unique sequence of range returns from internal structure of landmine

Concept Demonstrated on Real Data Taken with Wichmann Radar in Army Test Lanes



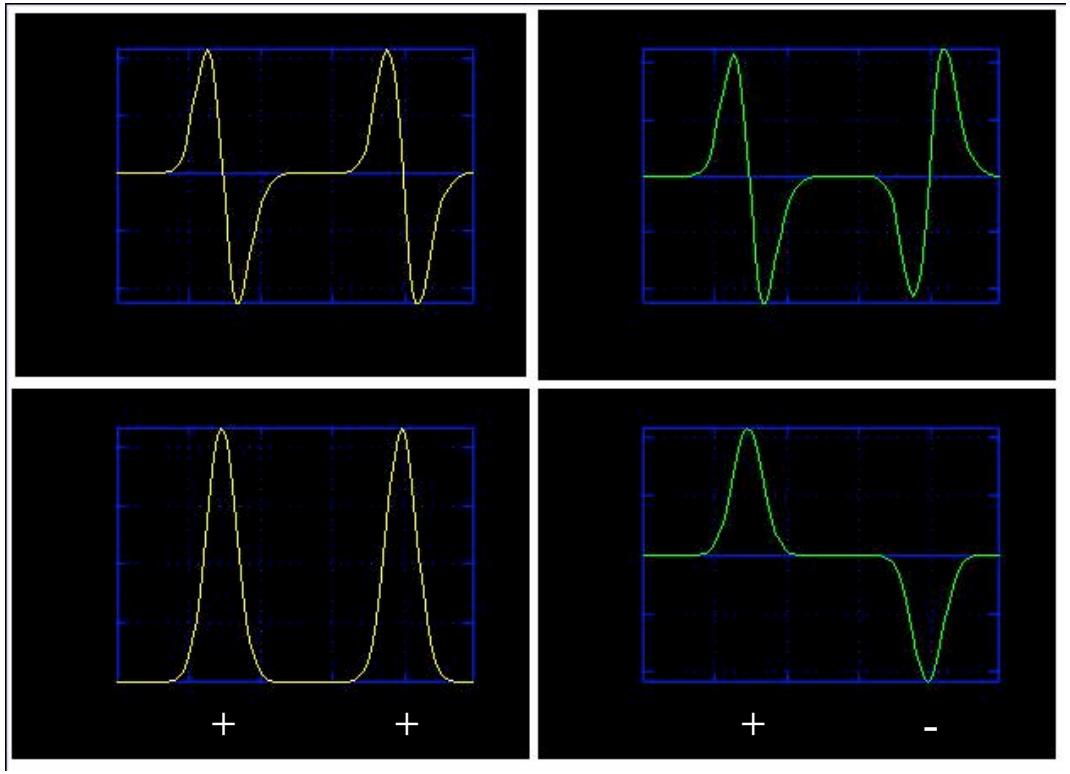
One column of data

Inverse Filtering of Superposed RADAR Returns of Increasing and Decreasing Dielectric, Δ Z

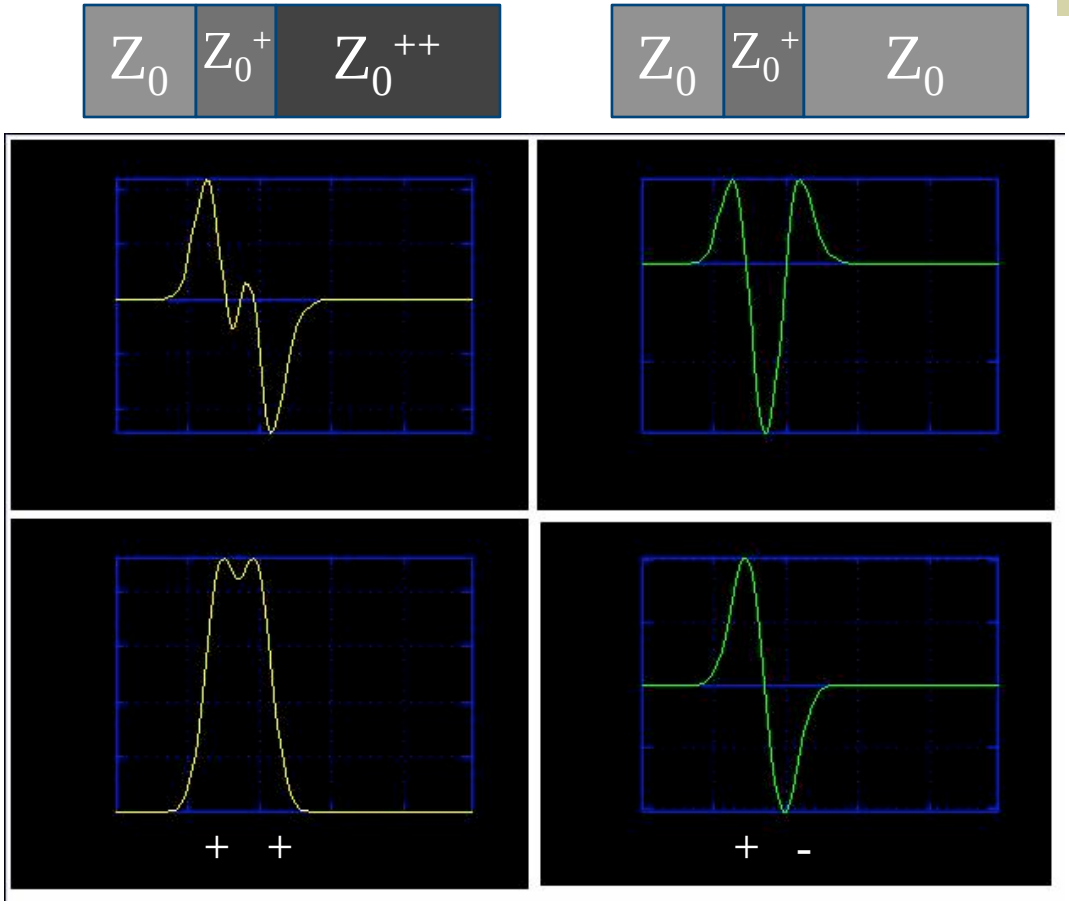
Material

Unprocessed Radar Signal

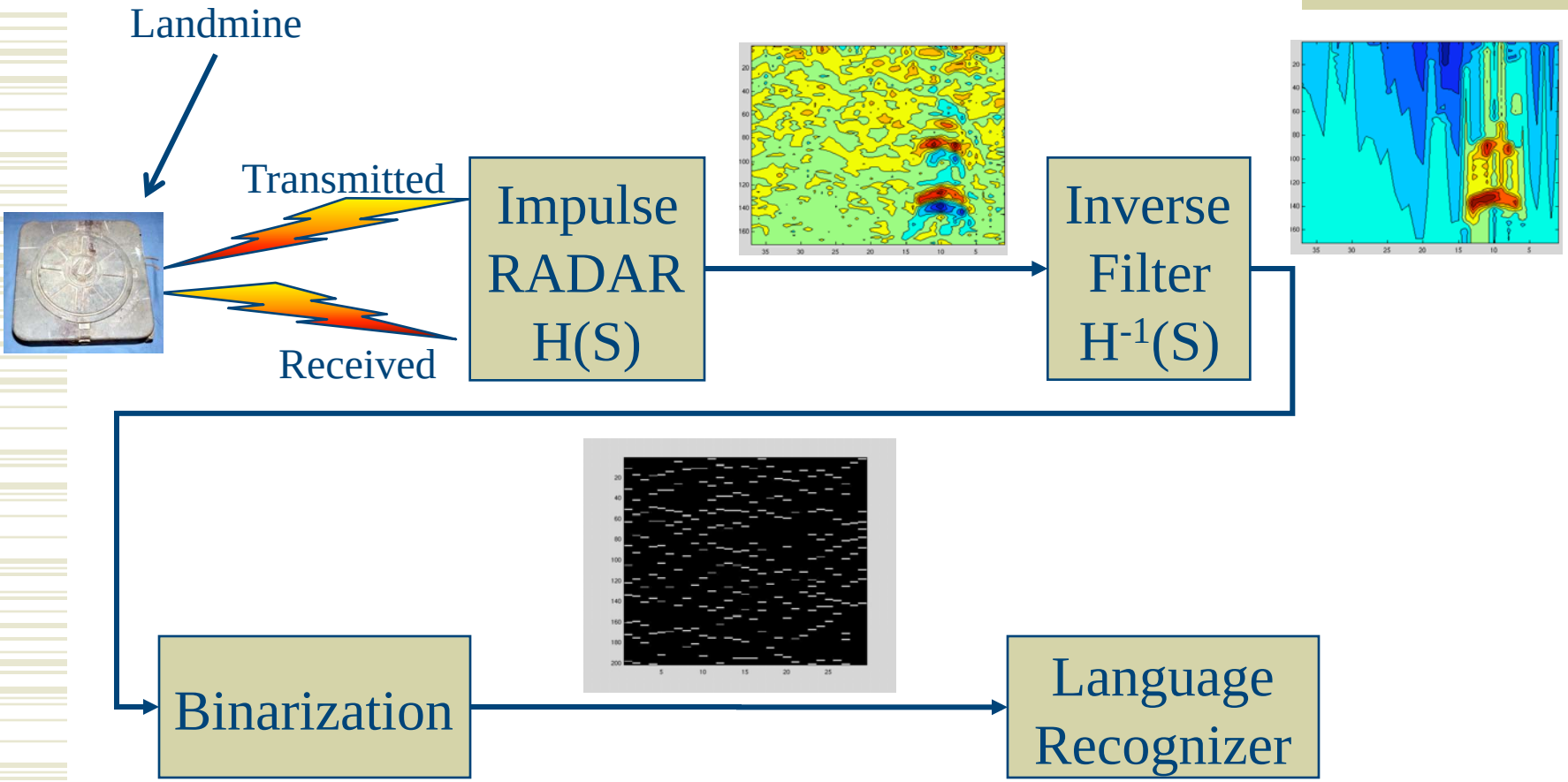
Inverse Filtered Signal



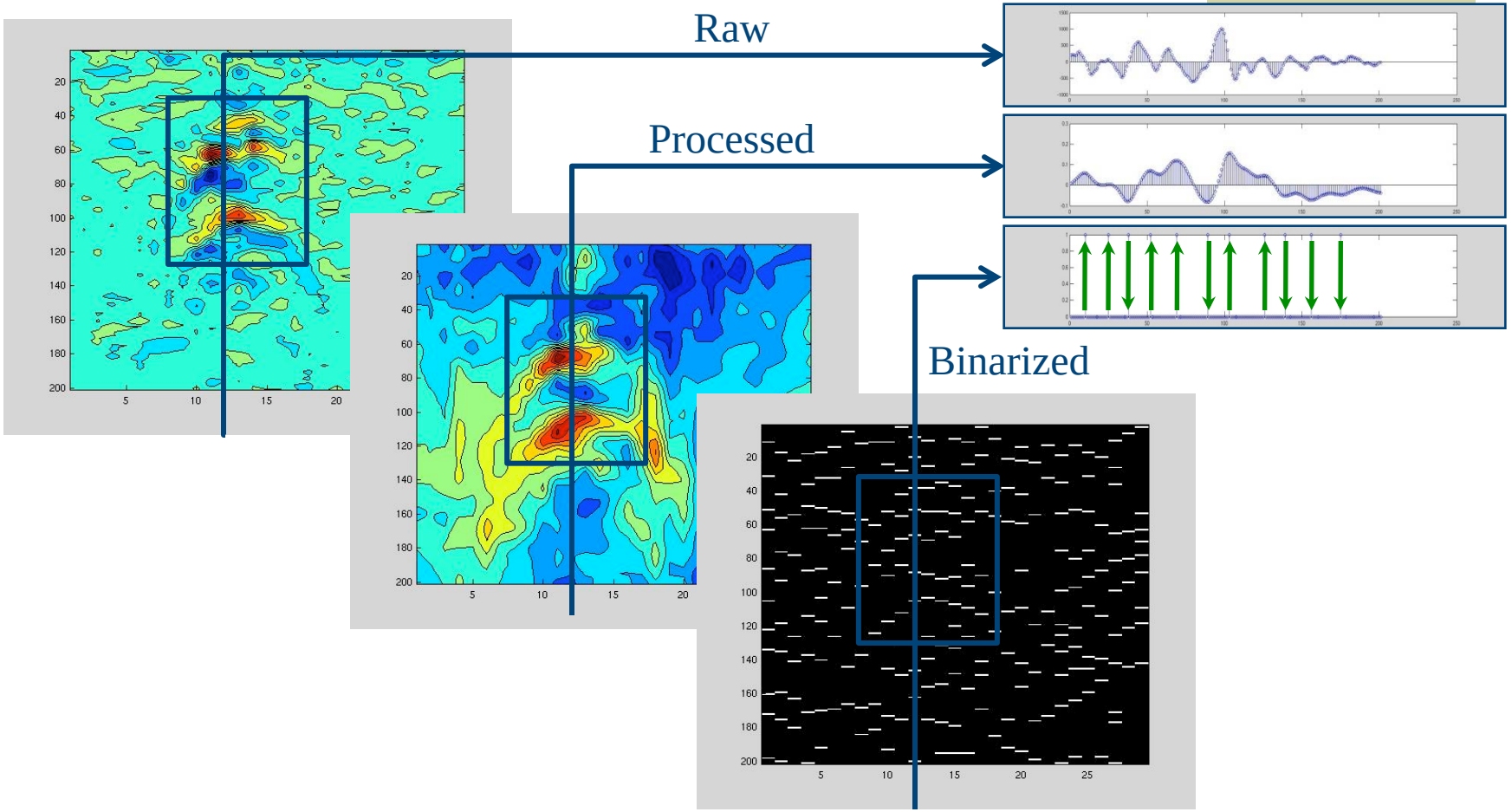
Inverse Filtering Improves Relative Range Measurement of Closely Spaced Δ Z's



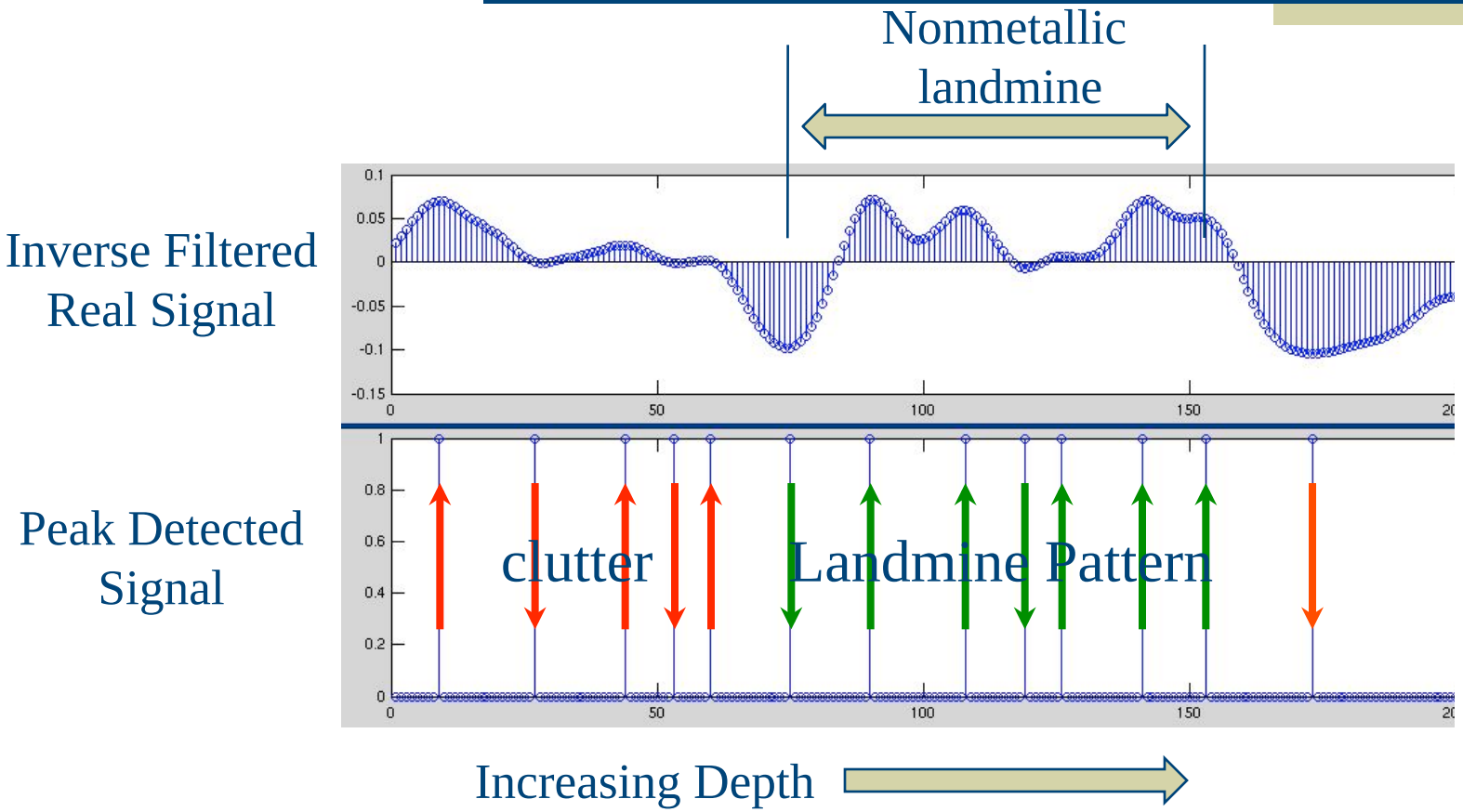
Processing Locates Changes in Materials Inside of Landmines



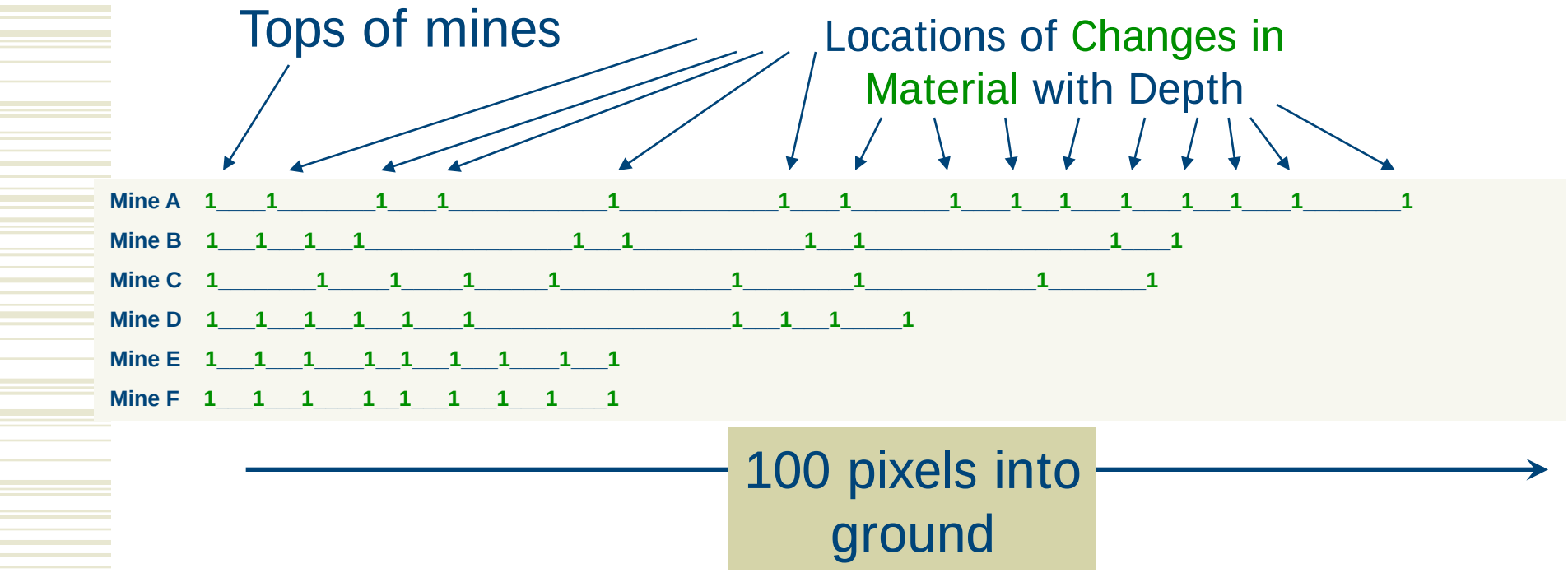
Preprocessing from Raw to Binarized GPR



+/- Peaks Indicate Locations of Changes in Material in One Column of Data



Processing of GPR Signals Yields "Strings" Which "Label" Landmines



Processing Produces Binary Valued String with Location of Landmine Impedance Changes

- The sequence of *1s* and *0s* which are a characteristic of each landmine can be considered to be a **binary valued word** embedded in a longer string of *1s* and *0s* , *e.g.*,

word = "1001001"

{ "10001000100001001000010010001000001" } ∈ L(Mine A)

- A set of strings can be considered to be a language, *e.g.*,

L = { "1010001", "1001001", "1000101" }

- A set of strings is, by definition, a **regular language**
- A regular language can be recognized by a **finite state machine** (FSM)
- An FSM recognizes words in a language **extremely fast** and in deterministic time while processing all data

A Regular Language Recognizer Is A Machine That Can Be Modeled As A Quintuple Of Sets

- *aka*, Rabin-Scott Automata (machine), automaton, language recognizer
- A recognizer ***M*** is a quintuple of sets

$$\mathrm{M} = \left(\mathbf{S}, \mathbf{I}, \delta, s_0, \mathbf{F} \right)$$

where

$$\mathbf{S} \equiv \left\{ s_0, s_1, s_2, \cdots, s_{n-1} \right\} \equiv \text{A finite set of states}$$

$$I \equiv \left\{ i_0, i_1, i_2, \cdots, i_{m-1} \right\} \equiv \text{A finite set of inputs}$$

$$\delta \equiv \mathbf{S} \times \mathbf{I} \rightarrow \mathbf{S} \subset \left\{ \left(\left(\mathbf{S} \times \mathbf{I} \right), S \right) \right\}$$

$$\equiv \left\{ \left(\left(s_a, i_b \right), s_c \right), \left(\left(s_d, i_e \right), s_f \right), \left(\left(s_g, i_h \right), s_i \right), \cdots \right\}$$

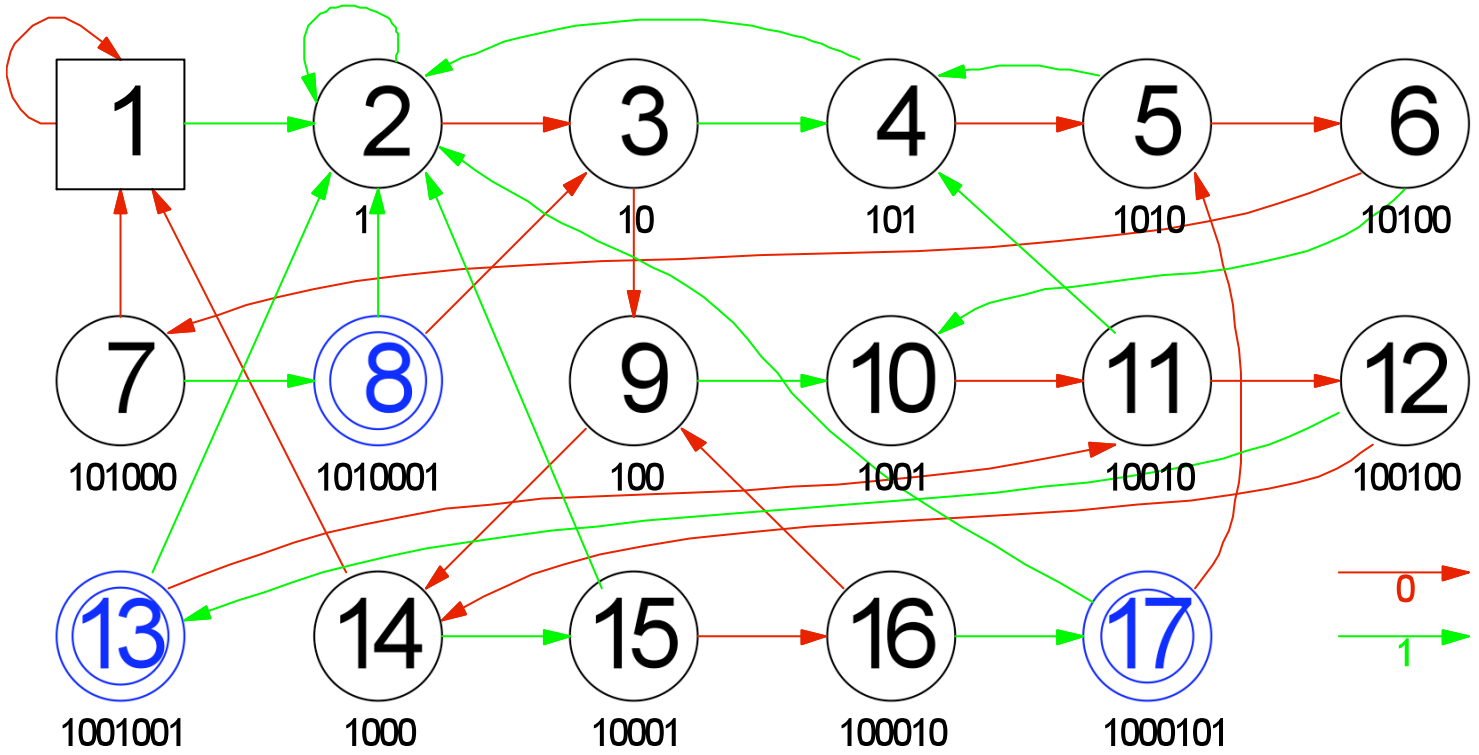
$$s_0 \equiv \text{the single, unique, starting state}$$

$$\mathrm{F} \equiv \left\{ s_p, s_q, \cdots \right\}$$

$$\equiv \text{A finite set of final states} \subseteq \mathbf{S}$$

Finite State Machine (FSM) Can Be Programmed to Recognize "Words" Characteristic of Mines

L={ 1001001, 1010001, 1000101 }



Implementation Methods for Recognizing the Language of Mines

- It is difficult to design an FSM landmine recognizer manually due to the large number of states (millions) when accounting for uncertainty of the location of *1's*, so we created FSM-maker program
  - FSM-maker has been implemented and verified
  - Requires new FSM for new mine
  - Current FSM-maker program can create a 5 million state FSM to recognize all 65,000 variations of a 100-bit string in less than one minute
- A behaviorally equivalent method is based on a major/minor state FSM
  - Only requires new landmine string, not redesign
  - Much smaller FSM which compares GPR string to template string

FSM Processing Is Extremely Fast Since Only One Clock Cycle Per Depth Cell

- Landmine detection speed is independent of the size of FSM since it only needs one clock cycle per range bin
- Hardware implementation in field programmable gate array (FPGA)
  - For a mine pattern length of 100, approximately 69 microseconds processing time per 24 x 416 voxels (~7 ns/voxel, ~145 MHz clock)
  - Alternative method of parallel binary correlators is faster, approximately 8 microseconds processing time per 24 x 416 voxels
- All data are processed in a deterministic amount of time

High Speed Syntactic Landmine Detection and Classification Has Extremely Low False Alarm Rate

For an example 74-bit string representing a typical antitank landmine

10000000000001000000000000000001000000000100000000000001000000000000100
10000000000011111000000000000011111000000111110000000001111100000000011111

- 2^{74} possible strings = $1.889 * 10^{22}$ (*e.g.* Nat'l Debt is $\$10^{13}$)
- Allowing for the deviation of an impedance discontinuity +\- 2 in depth
- Allowing one randomly placed noise pulse
- Number of acceptable strings: 6,250
- Number of states in FSM: 40,110
- If string is embedded in uniformly distributed white noise, there is one acceptable string for each of $3.022 * 10^{18}$ noise strings

Syntactic Landmine Detection is Fast, Effective, Capable

- **Fast**
  - The processing method has been implemented and demonstrated to operate at speeds equivalent to 40 mph and 60 mph processing speed is possible
- **Effective**
  - The processing method has been applied to real ground penetrating radar (GPR) data in various soil types and differentiated among several metallic and non-metallic anti-personnel (AP) and anti-tank (AT) landmines
  - The false alarm rate is extremely low
  - The processing depends on the internal structure of the landmine
- **Capable**
  - The processing method is readily expandable to other landmine types and other signal processing environments
  - The processing method is insensitive to ground bounce so it classifies landmines on the surface, partially buried, or completely buried
  - The processing method is computationally deterministic

Landmine Detection Vision

- Our new Language of Mines approach to landmine detection utilizing ground penetrating radars and identification of them through syntactic pattern recognition classification will make it so easy to detect landmines that
  - It will be possible to speed up the detection of already emplaced landmines and facilitate their remediation thereby eventually eliminating a man-made humanitarian tragedy
  - It will be economically unfeasible to emplace new landmines thereby minimizing the future threat of post-conflict landmines

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