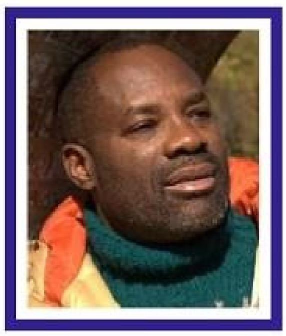
19 How I Solved the Toughest Problem in Physics



Philip Emeagwali Lecture 180123-2
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19.1.1 Emeagwali's Equations for Computational Physics

As a research computational mathematician of the 1970s and '80s

that executed supercomputer calculations
from Corvallis (Oregon, United States)
to Los Alamos (New Mexico, United States),
I believe that
they are more mathematical equations
to be yet discovered.
I believe that
they are partial differential equations
beyond the blackboard
and that has never been scribbled
on the blackboard.
For that reason, my quest
for a new internet
was motivated by my need
to execute the fastest
mathematical computations
and to execute the fastest
companion email communications
that must arise
while executing those computations
across my ensemble of 65,536 processors
that defined that new internet.
That quest

for the fastest mathematical computations
and email communications
was preceded by another quest
for the correct system of coupled, non-linear,
time-dependent, and state-of-the-art
partial differential equations
of modern mathematics
and extreme-scale computational physics.
Those partial differential equations
defined the initial-boundary value problem
of modern calculus
that was at the computational testbed
for my calculations
that I executed **across**
my global network of
65,536 processors
that, in turn, outlined and defined
a new internet.
That is, I wanted to go beyond
recording
the fastest computational speeds.
I wanted to record those speeds
across my new internet.

666

I wanted to **not only** record speeds
that were previously unrecorded
but to record those speeds
while solving the correct
partial differential equations.
Recording those speeds required that
I **mathematically discover**
the century-old mathematical error
that was unknown to
mathematical physicists
that formulated
the initial-boundary value problem
of modern calculus
that was at the mathematical foundation
of petroleum reservoir simulators.
To record those supercomputing speeds
required that I invent
the correct partial differential equations.
I invented
thirty-six [36] mathematical terms,
called partial derivatives that measure
changes in velocity, both in time and space
Those mathematical terms

encoded inertial forces
that were not accounted for
in the Second Law of Motion
of physics
and that were not coded
into petroleum reservoir simulators.
I contributed to modern algebra
by inventing
thirty-six [36] partial **difference** terms
of extreme-scale algebra
and computational physics.
Those algebraic terms
decoded, or discretized, the thirty-six [36]
partial **derivative** terms
that I invented.
Those terms defined the **nine**
partial **differential** equations
and defined the **nine**
partial **difference** equations
that I invented to approximate
the **new** partial **differential** equations
and that are called
the Emeagwali's Equations

and that could be used
by computational physicists
to simulate and enhance
the amount of crude oil and natural gas
that is discovered and recovered.

19.1.2 Stabilizing Unstable Computer Algorithms

I mathematically discovered
that research computational mathematicians
of the crude oil and natural gas industry
should go back to their blackboards
and correctly rederive their core equations
from first principle,
or from the Second Law of Motion
of physics.
The partial differential equation
of modern calculus
and computational physics
should speak its own truth.
But it should be a truth
that is legitimized
in its entirely

by the laws of physics
that the partial differential equation
expressed.
I mathematically discovered that
computational physicists
did not correctly derive
the system of partial differential equations
of the calculus
of petroleum reservoir simulation.
That system of partial differential equations
governs the subterranean motions of
crude oil, injected water, and natural gas
that flows from a water injection well
to an crude oil and natural gas production
well.
The incorrect partial differential equations
in computational physics textbooks
of the petroleum industry
is classified as parabolic.
However, I correctly rederived
and reclassified them as hyperbolic.
The incorrect system of
partial differential equations

in textbooks on porous media flow
do not point to an actual
initial-boundary value problem
of modern calculus.
In reality, the incorrect system of
partial differential equations
in calculus textbooks
detracts from the true
initial-boundary value problem
that gave birth to it.
The partial differential equation
must abstract
from the problem that it governs,
and not the problem
defined by the partial differential equation
that governs it.
For that reason, the thirty-six [36]
partial derivative terms
that I invented
were abstracted
from the crude oil, injected water, and
natural gas
that were in motion a mile-deep

and **across** the petroleum reservoir
that is being simulated.
The nine new partial differential equations
that I invented
were beings of reason
but what they simulated were real beings.
The reason I make this distinction
between beings of reason
and real beings
is because I am often asked:
"Did you discover or invent
Emeagwali's Equations?"
I answered that to discover
or to invent
is to see something, or to see an equation,
that was previously unseen
in any calculus textbook.
The answer is that I discovered
the **Emeagwali's Equations**
if my partial differential equations existed
in textbooks on modern calculus
and that I invented
the **Emeagwali's Equations**

if my partial differential equations
did not previously exist
in calculus textbooks.
I am the computational mathematician
that contributed
to the partial differential equations
of the calculus
that is used to **discover** and **recover**
otherwise **elusive**

crude oil and natural gas.
I contributed
to modern mathematical knowledge
by mathematically discovering
how to accurately derive
the correct system of
partial differential equations
of a new calculus
and of computational physics simulations
that governs
the subterranean motions of crude oil and
natural gas.
I correctly classified

those partial differential equations
as hyperbolic.
I corrected those critical errors
when calculus textbooks
incorrectly classified them
as parabolic, instead of hyperbolic.
My mathematical contributions
that is the new algebra
and the new calculus
that were at the foundation
of extreme-scale crude oil and natural gas
simulations
was headline stories
within the mathematics community,
as well as the cover story
of the May 1990 issue
of the *SIAM News*.
The *SIAM News*
is the top news journal of record
in the field of mathematics.
The *SIAM News*
is published by the Society for Industrial
and Applied Mathematics.

In the May 1990 issue
of the *SIAM News,*
I explained to research mathematicians
that my diagonal matrix—that had
24 million by 24 million
mostly zero entries—
was a world record
in extreme-scale algebra of 1989.
That diagonal system of equations
of algebra
allowed for a ruthlessly pared down
computer code.
I used emails to distribute
my sixty-five thousand
five hundred and thirty-six [65,536]
computer codes
to my ensemble of
sixty-five thousand
five hundred and thirty-six [65,536]
commodity processors.
Those processors
were identical.
Those processors

were equal distances apart
from each other.
Those processors
were the building blocks
of a new supercomputer.
Those processors
outlined a new internet
that I visualized
as encircling a globe
in a sixteen-dimensional hyperspace.
Each processor
was my metaphor for a computer
and was at a node
within my global network of
65,536 processors
and was my small copy of the Internet.

19.1.3 Opening the Doors to Many Things

At 10:15 in the morning NewYork Time
Tuesday the Fourth of July 1989,
the US Independence Day,

I made the first measurement
of the world's fastest computation
ever recorded **across**
an ensemble of commodity-off-the-shelf
processors.
That discovery represents a new way
of looking at the computer.
In the new way, the new computer
would become a web of a million
interconnected processors
and the new computer
would have as many email pathways
by which its ensemble of processors
communicate.
To be the first
is a greater achievement
than to be number one
or to be the fastest.
There's only one first
but they will be many fastest.
I was the first to discover
that parallel processing **across**
an ensemble of the slowest processors

is faster than sequentially processing
only on the fastest processor,
or only on the fastest supercomputer.
Prior to my discovery
of the massively parallel processing
supercomputer
that occurred on the Fourth of July 1989,
I was ridiculed, mocked, and rejected
by the vector processing supercomputer
research community.
After my discovery
of the Fourth of July 1989,
the last team of vector processing
supercomputer researchers
that dismissed me from their group
realized that they've made a mistake.
Their mistake entered into the history books.
A year later, a member
of the supercomputer research team
that dismissed me from their research group
told the rest
that his daughter wrote a school report
titled:

[quote]
"The Contributions of **Philip Emeagwali**
to the Development of the Computer."
[unquote]
After the Fourth of July 1989,
it made the news headlines that
I experimentally discovered
how and why
the parallel processing technology
makes modern computers **faster**
and makes the new supercomputer
the **fastest**.
My discovery
of the parallel processing supercomputer
opened the door
to the field of the parallel solution
of the numerical approximations
of the partial differential equations
of modern calculus
that now enables
extreme-scale computational
mathematicians
to massively parallel compute

many algebraic problems
and to compute them **at once.**
My discovery
of the parallel processing supercomputer
opened the door
to the field of parallel
computational fluid dynamics
that now enables extreme-scale
computational physicists
to massively parallel compute
many computer models
and to compute them **at once**.
My discovery
of the parallel processing supercomputer
opened the door
to the field of large-scale
numerical algebra,
that now enables algebraists
to solve millions of sets of
systems of linear equations
and to solve them **at once**.
The modern supercomputer
opened the door

to the field of experimental mathematics,
and to using the fastest supercomputer
to confirm analytical solutions
and to using the fastest supercomputer
to gain insight and intuition
into a mathematical problem
and to using the fastest supercomputer
to test and falsify
a mathematical conjecture.
The modern supercomputer
that is powered by
massively parallel processing technology
is an instrument of physics
that extreme-scale computational physicists
use to solve the most
computation-intensive
arithmetical problems.
The computation-intensive problems
of supercomputing
arose from
extreme-scale algebra
that, in turn, arose from
the most abstract

partial differential equations
of modern calculus.
Parallel computing
can best be explained to a twelve-year-old
as "doing many things
at once."
I was in the news, back in 1989,
because I discovered
how to do
64 binary thousand things
and how to do them **at once**.
My discovery
of how to massively parallel process
and how to do so
across 64 binary thousand processors
opened the door
that enables
the world's fastest supercomputer
to parallel process 10 binary million things
and to parallel process them **at once**.

19.1.4 My Quest for Parallel Processing

For me, **Philip Emeagwali**,
my quest for the experimental discovery
of the parallel processing supercomputer
began on June 20, 1974.
My quest for the fastest
parallel processing supercomputer
began with one of the world's fastest
sequential processing supercomputer
that was, in June 1974,
inside the Computer Center
that was at 1800 SW Campus Way,
Corvallis, Oregon, United States.
My quest
was for the new knowledge,
or for the discovery,
of how to **compound** an ensemble of
processors, or computers.
My quest
was for how to **compound**
sixty-five thousand
five hundred and thirty-six [65,536],
or two-raised-to-power sixteen,
processors,

or compound as many computers.
My quest
was for how to compound processors,
or computers,
and how to compound them repeatedly
and how to continue **compounding**
processors
to form a seamless, cohesive supercomputer.
My quest
was for how to continue **compounding**
processors
and for how to do so **across**
the surface of a globe
that I visualized as **embedded**
into a sixteen-dimensional universe.
My quest
was for how to continue **compounding**
processors
and for how to continue until I had
a global network of
64 binary thousand
processors.
That's how I—**Philip Emeagwali**—

discovered my small internet
that is a global network of processors.
On June 20, 1974, and at age 19,
I was like a mouse
crawling inside the Computer Center
that was at 1800 SW Campus Way,
Corvallis, Oregon, United States.
Over the next decade and half,
I grew into a 34-year-old lion protecting
the world's fastest supercomputer.
I grew to invent a new supercomputer
that is called the
Philip Emeagwali computer
that is a global network of processors.
I grew to invent a new internet
that is called the
Philip Emeagwali internet.
I was invisible in 1974
but I am now visible everywhere
on the internet.
Looking back, the supercomputer center
was a lonely place
be a young black computer wizard.

19.1.5 Rejections and Final Acceptance

The **small internet**
that I discovered
was my prototype
of a planetary-sized Internet.
That small-scaled internet
was powered by 64 binary thousand
commodity processors.
The experimental discovery
that I made **across**
that small-scaled internet
made the news headlines
in 1989
and it inspired the development
of the modern parallel processing
supercomputer
that is powered by
up to ten million
six hundred and forty-nine thousand
six hundred [10,649,600]
commodity processors.

My theoretical discovery
of massively parallel processing
was ignored for the decade
that preceded 1989.
I gave a massively parallel processing
supercomputer lecture
in November 1982.
I gave the supercomputer lecture
in a conference auditorium
that was a short walk from
The White House,
Washington, D.C.,
The abstract of my supercomputer lecture
described my theoretical discovery
of the massively parallel processing
supercomputer.
Only one computational physicist
attended that supercomputer lecture.
Those research physicists
that did not attend my lecture
of November 1982
joked that parallel processing
is a beautiful theory that lacked

experimental confirmation.
My theoretical discovery
of the massively parallel processing
supercomputer
was only accepted, in 1989.
It was accepted
after I had experimentally re-confirmed
massively parallel processing
and re-confirmed it **across**
a new internet
that is a global network of
sixty-five thousand
five hundred and thirty-six [65,536]
commodity processors.
After a decade of directed effort,
my theoretical discovery
of the massively parallel processing
supercomputer
was confirmed experimentally
on the Fourth of July 1989,
and confirmed by me—**Philip Emeagwali**.
To experimentally discover
the massively parallel processing

supercomputer,
I had to combine physics insight
that enabled me to invent
partial differential equations
of a new calculus
that I discretized
into a large system of equations
of a new algebra.
I discovered
how to solve that large-scale system
of equations
and how to solve it **across**
a small internet.
I visualized that small internet
as my global network of
64 binary thousand processors,
or as a global network of
as many computers.

19.1.6 My Contributions to Physics

My contribution to physics
is this:
Before my discovery
of the massively parallel processing
supercomputer
that occurred on the Fourth of July 1989,
the most extreme-scale
computational physics codes
were only executed on only one
supercomputer.
After my discovery
of the massively parallel processing
supercomputer
the most extreme-scaled
computational physics codes
were only executed **across**
millions upon millions
of commodity-off-the-shelf processors.
The precondition
to discovering
how to execute
the fastest computations **across**
my ensemble of processors

and how to do so
as one seamless, cohesive unit
that is a new supercomputer
and that is a new internet
required that I invent new techniques
for sending emails
that I visualized
as having five-subject lines
and receiving emails
that I visualized
as having three-subject lines
and sending and receiving those emails
to and from
two-to-power sixteen,
or 65,536, sixteen-bit long
email addresses,
each with no @ sign
or dot com suffix.
In the 1980s, the Department of Energy
of the United States government
classified the most extreme-scaled problems
in computational physics
as grand challenges in supercomputing

and as the toughest problems in physics.
For me, **Philip Emeagwali**, to solve the
grand challenge problem
that was described as extreme-scale
petroleum reservoir simulation
demanded that I be able to extend
the frontiers of modern calculus
and extend that frontier of knowledge
by a distance of
nine partial differential equations
of modern calculus
and also extend
the frontier of modern algebra
by a distance of
nine partial difference equations
and extend both frontiers of knowledge
from the blackboard
to the motherboard
and then extend those frontiers
of knowledge **across**
an ensemble of
two-to-power sixteen processors
that were married together

as one cohesive whole unit
and married by sixteen times
two-to-power sixteen, or 1,048,576,
bi-directional email wires.
Those email wires
has a **one-to-one** correspondence
to the as many bi-directional edges
of the hypercube
in the sixteenth-dimensional hyperspace.
That is, the lone wolf inventor
of the new supercomputer
that is a new internet
must be a jack-of-all-sciences.
The lone wolf inventor of that new internet
must be a renaissance person
that is a multidisciplinary threat
that can simultaneously extend
the boundaries of human knowledge
and extend that boundary
across computational physics,
modern calculus, extreme-scale algebra,
fastest supercomputer, and a new internet.

19.1.7 The Land Before Parallel Processing

In summary, **we knew**
the land before parallel processing
and we named that land
sequential processing,
or computing only one thing **at a time**.
We knew the most important laws in physics
and we knew them
three centuries and three decades ago.
We knew how to encode
those laws of physics
as the most advanced expressions
in calculus
called partial differential equations
and we knew them
nearly a century and a half ago.
We knew how to discretize
those partial differential equations
to their algebraic approximations
and we knew them
almost a century ago.
We knew how to further reduce

the systems of equations of algebra
and how to reduce them
to an equivalent set of
floating-point arithmetical operations
and we knew them
over half a century ago.
We had been executing
those floating-point arithmetical operations
since 1946,
the year the first digital, programmable
supercomputer
was invented.
We knew the land before
parallel processing
as the land where we computed
one thing **at a time**.

19.1.8 The Land After Sequential Processing

In the 1980s, we did not know
the land after sequential processing,
or computing many things

at a once.
What made the news headlines
in 1989
was that I did something
that was considered physically impossible
to do, namely, I crossed from
the land of sequential processing
to the land of parallel processing.
What made the news headlines
was that I discovered
how to solve
the most computation-intensive problems
of extreme-scale computational physics.
On the Fourth of July 1989,
I discovered
how to solve
those grand challenge problems
and how to solve them **across**
sixty-five thousand
five hundred and thirty-six [65,536]
commodity-off-the-shelf processors,
or across as many identical computers
that outline a small internet.

The supercomputing community
confirmed my discovery
and the June 20, 1990 issue
of *The Wall Street Journal* recorded that
I—**Philip Emeagwali**—
had discovered
that we can massively parallel process
and that I discovered it
via emails I sent to
sixteen-bit long addresses
that each had no @sign
or dot com suffix
and via emails I received **across**
a small internet.
That small internet, is a global network
of sixty-five thousand
five hundred and thirty-six [65,536]
commodity processors,
or as many identical computers.
Finally, I must add that
solving the grand challenge problem
of computational physics
sharpened and **deepened**

our understanding of both the computer
and the supercomputer,
and changed the way we look
at both technologies.

19.1.9 Thirty Thousand Years in One Day

The modern supercomputer
that computes **faster**
by massively parallel processing **across**
millions of processors
is the **fastest** computer in the world.
The massively parallel supercomputer
became the world's **fastest** computer
by computing many things
at once,
instead of computing only one thing
at a time.
The modern supercomputer
that solves millions of problems

at once,
instead of solving only one problem
at a time
helps make the world
a more knowledgeable place.
The modern supercomputer
that reduced **time-to-solution**
from thirty thousand [30,000] years
to just one day
increased our understanding
of our universe.
My discovery
of how to reduce **time-to-solution**
and how to reduce it
from 180 years to just one day
opened the door
to the modern supercomputer
that inspired the reduction
of **time-to-solution**
from thirty thousand [30,000] years
to just one day.

19.1.10 More Information

I'm Philip Emeagwali.
I've posted at emeagwali dot com
the complete version of this lecture.
Go to my website
and look for my videotaped
lecture series
on how I experimentally discovered
that massively parallel processing
could be harnessed
as the driving force
of the computer and the internet.
That discovery paved the way
for the modern computer.

19.1.11 Why I Videotaped My Lectures

For me, **Philip Emeagwali**,
I find it unsettling
to see a modern inventor
that did not articulate his invention
in videotaped lectures.
These modern inventors
never left a video-taped recording
of how they invented
and what they invented.
The absence of videotaped lectures
reduces discussions of their inventions
to endless **he-said**, **she-said**.

19.1.12 Following the Footsteps of My Distant Ancestors

About four centuries ago,
my most distant ancestor
—that I know by name,
named **Eze Chima**,

lived in present day Nigeria (West
Africa).
Eze Chima
led a human wave of refugees
that were fleeing from
the tyrannical rule of
Oba Esigie [1504-1550], or King, of Benin
and his slave raiders
that sought slaves
for the earliest slave traders,
such as the Englishman
John Hawkins
who sold my ancestors
off to the island of Hispaniola
meaning "little Spain."
That island that was near Haiti
was [quote unquote] "**discovered**"
by **Christopher Columbus**
and discovered
on the Fifth of December of 1492.
Some of my ancestors

were captured by the Oba of Benin
and survived
the Middle Passage **across**
the Atlantic Ocean.
The African names of my ancestors
that crossed the Atlantic Ocean,
such as those named **Emeagwali**,
were lost in the mist of time.
My ancestors that were captured
as slaves
are in the 200 million African diaspora
that are living in countries like
Brazil, Jamaica, and the United States.
Eze Chima and some of my ancestors
that escaped from the slave raiders
fled towards Onitsha, in modern day
Nigeria.
Onitsha
is my ancestral hometown
in Igbo Land.
Eze Chima fled from the slave raiders

and fled with no map
to guide him in his flight
from Benin to Onitsha, Igbo Land.
The big question, or the *terra incognita*,
for **Eze Chima** was:
"What lied beyond Igbo Land?"
To **Eze Chima**,
the Atlantic Ocean, was a *terra incognita,*
called *ani ndi mmuo*
or the Land of the Spirits.
The Atlantic Ocean
was a ???? 150-mile boat ride
from the River Niger at Onitsha.
Back in the 16th century,
the Atlantic Ocean
was vast and endless.
And crossing the Atlantic Ocean
was my metaphor
for experimentally discovering
how to harness
the total supercomputing power

of my ensemble of 65,536 processors.
I began programming supercomputers
on June 20, 1974
in Corvallis, Oregon, United States
and at age nineteen.
As a nineteen-year-old
supercomputer programmer,
I felt like the child
that was put in command
of an ocean liner.
At its core, my biggest question
was the same for Eze Chima.
The big question for **Eze Chima** was:
"Who will climb
into a dugout canoe
at the banks of the River Niger
at Onitsha
and paddle the canoe
to find out where the world ends?"
Who will find out
where the River Niger began?

Or where the River Niger ended?
Who will visit the kingdom
at the bottomless ocean floor
that is the home of the mermaid,
called "Mami Wata" or *eze nwanyi mmiri*.
The big question for the distant
descendant
of **Eze Chima**, **Philip Emeagwali,**
who voluntarily came to the Americas
by plane,
not involuntarily by ship, was
"Can an ensemble
of the slowest processors
outperform the fastest supercomputer
and change the way
we look at the modern computer?"
For the fifteen years
onward of June 20, 1974,
this parallel processing research project
kept me up at night.
In the final days

leading to the experimental discovery
of massively parallel processing,
a discovery that occurred
on the Fourth of July 1989,
I had my heart in my throat.
I had the visceral feeling
that my massively parallel processing
supercomputer results
were historic.
That experimental discovery
of the massively parallel processing
supercomputer
is the reason children
are writing school reports titled:
"The Contributions
of **Philip Emeagwali**
to the Development of the Computer."
I am an African-born
computational mathematician
that followed
in the footsteps of ancient African-born

mathematicians.
The oldest mathematics literature
was excavated in Africa
and it was written 1550 B.C.
and it was written by **Ahmes**.
The African mathematician named **Euclid**
is the father of geometry.
And as far as the historical records
reveal,
the 2,300 year-old DNA of **Euclid**
originated from Africa.
And 2,300 years later,
the DNA of **Euclid** remains in Africa.
Euclid lived in North Africa
and lived at a time
North Africa was predominately black.
As a torch bearer
I had to give voice
to my voiceless ancestors.
And I had to construct
the narrative of Africa's contributions

to mathematical knowledge.
That was how I—**Philip Emeagwali**—
became the bearer
of Africa's contributions
to human knowledge.