

# Goldbach's Conjecture — Towards the Inconsistency of Arithmetic

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**Abstract.** This paper proves an inconsistency in Peano arithmetic (PA). We express a strengthened form of the strong Goldbach conjecture using a specific set. This set varies according to whether the conjecture or its negation is assumed. We show that, on the other hand, the set remains unchanged under these two assumptions. This causes a contradiction.

**Notations.** Let  $\mathbb{N}$  denote the natural numbers starting from 1, let  $\mathbb{N}_a$  denote the natural numbers starting from  $a > 1$  and let  $\mathbb{P}_3$  denote the prime numbers starting from 3.

Strengthened strong Goldbach conjecture (SSGB): *Every even number greater than 6 is the sum of two different odd primes.*

**Theorem.** *PA is inconsistent.*

*Proof.* Assuming that PA is consistent, we will show that the statement FALSE can be deduced.

We define the set  $S_g := \{ (pk, mk, qk) \mid k, m \in \mathbb{N}; p, q \in \mathbb{P}_3, p < q; m = (p + q) / 2 \}$ .

The term  $S_g$  is not a standard part of PA, but it can easily be defined within PA.

SSGB is equivalent to saying that every integer  $n \geq 4$  is the arithmetic mean of two different odd primes and so it is equivalent to saying that all integers  $n \geq 4$  appear as  $m$  in a middle component  $mk$  of  $S_g$ . So, by the definition of  $S_g$  we have

$$\begin{aligned} \text{SSGB} &\Leftrightarrow \forall n \in \mathbb{N}_4 \exists (pk, mk, qk) \in S_g \quad n = m \\ \neg\text{SSGB} &\Leftrightarrow \exists n \in \mathbb{N}_4 \forall (pk, mk, qk) \in S_g \quad n \neq m. \end{aligned}$$

The set  $S_g$  has the following two properties.

First, the whole range of  $\mathbb{N}_3$  can be expressed by the triple components of  $S_g$  ("covering"). We prove this by dividing it into the following three cases.

- (i)  $x \in \mathbb{N}_3$  is prime. Then,  $x = pk$  with  $p \in \mathbb{P}_3$ ,  $k = 1$ .
- (ii)  $x \in \mathbb{N}_3$  is composite and not a power of 2. Then,  $x = pk$  with  $p \in \mathbb{P}_3$ ,  $k \neq 1$ .
- (iii)  $x \in \mathbb{N}_3$  is a power of 2. Then,  $x = (p + q)k / 2$  with  $p = 3$ ,  $q = 5$ ,  $k = (\text{a power of } 2)$ .

So we have

$$(C) \forall x \in \mathbb{N}_3 \exists (pk, mk, qk) \in S_g \quad x = pk \vee x = mk.$$

A few examples of the covering:

$$x = 19: (19 \cdot 1, 21 \cdot 1, 23 \cdot 1), (19 \cdot 1, 60 \cdot 1, 101 \cdot 1)$$

$$x = 27: (3 \cdot 9, 7 \cdot 9, 11 \cdot 9)$$

$$x = 42: (3 \cdot 14, 5 \cdot 14, 7 \cdot 14), (7 \cdot 6, 9 \cdot 6, 11 \cdot 6)$$

$$x = 4096: (3 \cdot 1024, 4 \cdot 1024, 5 \cdot 1024)$$

$$x = 10000: (5 \cdot 2000, 6 \cdot 2000, 7 \cdot 2000).$$

Second, all pairs  $(p, q)$  of distinct odd primes are used in the definition of the set  $S_g$  ("maximality"). So we have

$$(M) \forall p, q \in \mathbb{P}_3, p < q \quad \forall k \in \mathbb{N} \quad (pk, mk, qk) \in S_g, \text{ where } m = (p + q) / 2.$$

$\neg(C)$  would immediately imply  $\neg$ SSGB since an  $n \geq 4$  that is different from all  $S_g$  triple components  $pk$  and  $mk$  is in particular different from all  $m$  in  $S_g$ . So the property (C) excludes this possibility.

The property (M) excludes the possibility that if there is an  $n \geq 4$  different from all  $m$  in  $S_g$ , then  $n$  is the arithmetic mean of a pair of distinct odd primes not used in  $S_g$ . So (M) rules out the possibility that the question of whether SSGB holds or not depends on whether (M) holds or not. (The proof would no longer be possible if we left out any pair of distinct odd primes in the formulation of SSGB and  $S_g$ .)

Therefore, in both cases SSGB and  $\neg$ SSGB, neither  $\neg(C)$  nor  $\neg(M)$  applies.

The basic idea is now the following.

*There are two possibilities for  $S_g$ , exactly one of which must occur: Either there is an  $n \in \mathbb{N}_4$  in addition to all the numbers  $m$  defined in  $S_g$  or there is not. The latter is equivalent to SSGB and the former is equivalent to  $\neg$ SSGB.*

*Since, due to (M), an  $n \in \mathbb{N}_4$  different from all  $m$  cannot be the arithmetic mean of a pair of primes not used in  $S_g$  and since, due to (C), this  $n$  equals a component of some  $S_g$  triple that exists by definition, the covering of  $\mathbb{N}_3$  by the  $S_g$  triples in the case  $n$  exists ( $\neg$ SSGB) is equal to that in the case  $n$  does not exist (SSGB). This causes a contradiction because in the case SSGB the numbers  $m$  defined in  $S_g$  take all integer values  $x \geq 4$  whereas in the case  $\neg$ SSGB they don't.*

The following steps are independent of the choice of  $n$  if, in the case of  $\neg$ SSGB, there is more than one that is different from all  $m$ . For example, the minimal such  $n$  works.

We split  $S_g$  into two complementary subsets in the following way. For any  $y \in \mathbb{N}_3$ , we write

$S_g = S_{g+(y)} \cup S_{g-(y)}$ , with

$S_{g+(y)} := \{ (pk, mk, qk) \in S_g \mid \exists k' \in \mathbb{N} \quad pk = yk' \vee mk = yk' \vee qk = yk' \}$

$S_{g-(y)} := \{ (pk, mk, qk) \in S_g \mid \forall k' \in \mathbb{N} \quad pk \neq yk' \wedge mk \neq yk' \wedge qk \neq yk' \}$ .

We define

$S_1 := \{ (pk, mk, qk) \in S_g \mid \text{SSGB} \}$

$S_2 := \{ (pk, mk, qk) \in S_g \mid \neg\text{SSGB} \}$ .

Under the assumption  $\neg$ SSGB there is an  $n \in \mathbb{N}_4$  as described above and under the assumption SSGB there is no such  $n$ . Then, since under both assumptions SSGB and  $\neg$ SSGB the possibilities  $\neg$ (C) and  $\neg$ (M) are both excluded,

$$(\forall y \in \mathbb{N}_3 \quad \text{SSGB} \Rightarrow S_1 = S_{g+(y)} \cup S_{g-(y)})$$

(1)  $\wedge$

$$(\neg\text{SSGB} \Rightarrow S_2 = S_{g+(n)} \cup S_{g-(n)}).$$

Since  $S_{g^+}(n) \cup S_{g^-}(n)$  is independent of  $n$ , we get

$$(\forall y \in \mathbb{N}_3 \quad \text{SSGB} \Rightarrow S_1 = S_{g^+}(y) \cup S_{g^-}(y))$$

(1')  $\wedge$

$$(\forall y \in \mathbb{N}_3 \quad \neg \text{SSGB} \Rightarrow S_2 = S_{g^+}(y) \cup S_{g^-}(y)).$$

Now, we will make use of the following principle.

If two sets of (possibly infinitely many)  $z$ -tuples are equal, then the sets of their corresponding  $i$ -th components are equal;  $1 \leq i \leq z$ .

To this end, for each  $k \in \mathbb{N}$  we define

$$M_1(k) := \{ mk \mid (pk, mk, qk) \in S_1 \}$$

$$M_2(k) := \{ mk \mid (pk, mk, qk) \in S_2 \}.$$

Then, applying the principle above to the middle component of the triples  $(pk, mk, qk)$ , (1') implies

$$(\forall k \in \mathbb{N} \quad \forall y \in \mathbb{N}_3 \quad \text{SSGB} \Rightarrow M_1(k) = \{ mk \mid (pk, mk, qk) \in S_{g^+}(y) \cup S_{g^-}(y) \})$$

(2)  $\wedge$

$$(\forall k \in \mathbb{N} \quad \forall y \in \mathbb{N}_3 \quad \neg \text{SSGB} \Rightarrow M_2(k) = \{ mk \mid (pk, mk, qk) \in S_{g^+}(y) \cup S_{g^-}(y) \}).$$

Setting  $M_1 := M_1(1)$  and  $M_2 := M_2(1)$ , we get

$$(\forall y \in \mathbb{N}_3 \quad \text{SSGB} \Rightarrow M_1 = \{ m \mid (p, m, q) \in S_{g^+}(y) \cup S_{g^-}(y) \})$$

(2')  $\wedge$

$$(\forall y \in \mathbb{N}_3 \quad \neg \text{SSGB} \Rightarrow M_2 = \{ m \mid (p, m, q) \in S_{g^+}(y) \cup S_{g^-}(y) \}).$$

Since for every  $y \in \mathbf{N}_3$   $S_{g^+}(y) \cup S_{g^-}(y)$  equals  $S_g$  by definition, for every  $y \in \mathbf{N}_3$   $\{ m \mid (p, m, q) \in S_{g^+}(y) \cup S_{g^-}(y) \}$  equals the set  $M := \{ m \mid (p, m, q) \in S_g \}$ . So, from (2') we obtain

$$(3) (SSGB \Rightarrow M_1 = M) \wedge (\neg SSGB \Rightarrow M_2 = M).$$

$M$  is a bound variable that equals either  $\mathbf{N}_4$  if  $SSGB$  is true or some non-empty proper subset  $Y$  of  $\mathbf{N}_4$  if  $SSGB$  is false.

Now, we make use of the following rule.

Let  $P = P(A)$  be a proposition that depends on a set  $A$ . Then, for any set  $B$ ,

( we have a proof of  $P(A) \wedge$  we have a proof of  $(P(A) \Rightarrow P(B))$  )  $\Rightarrow$  we have a proof of  $P(B)$ .

In the special case that  $A$  is a variable that is replaced by  $B$ , we have

( we have a proof of  $P(A) \wedge$  we have a proof of  $((P(A) \wedge A = B) \Rightarrow P(B))$  )  $\Rightarrow$  we have a proof of  $P(B)$ ,

which gives

we have a proof of  $P(A) \Rightarrow$  we have a proof of  $P(B)$ .

Since (3) depends on the variable  $M$  and since we have a proof of (3), we can apply the above rule with  $P = (3)$ . If  $M = \mathbf{N}_4$  we use the rule with  $A = M$  and  $B = \mathbf{N}_4$ , and if  $M = Y$  we use it with  $A = M$  and  $B = Y$ . Then, since either  $M = \mathbf{N}_4$  or  $M = Y$ , from (3) we obtain

$$(3.1) \text{ we have a proof of } (SSGB \Rightarrow M_1 = \mathbf{N}_4 \wedge \neg SSGB \Rightarrow M_2 = \mathbf{N}_4)$$

$\vee$

$$(3.2) \text{ we have a proof of } (SSGB \Rightarrow M_1 = Y \neq \mathbf{N}_4 \wedge \neg SSGB \Rightarrow M_2 = Y \neq \mathbf{N}_4).$$

This implies

**(3.1')** ( we have a proof of ( SSGB  $\Rightarrow$   $M_1 = \mathbf{N}_4$  )  
 $\wedge$   
we have a proof of (  $\neg$ SSGB  $\Rightarrow$   $M_2 = \mathbf{N}_4$  ) )

$\vee$

**(3.2')** ( we have a proof of ( SSGB  $\Rightarrow$   $M_1 = Y \neq \mathbf{N}_4$  )  
 $\wedge$   
we have a proof of (  $\neg$ SSGB  $\Rightarrow$   $M_2 = Y \neq \mathbf{N}_4$  ) ).

Now, we will establish a contradiction to ( (3.1')  $\vee$  (3.2') ).

Under the assumption SSGB the set  $M = \{ m \mid (p, m, q) \in S_g \}$  is equal to  $\mathbf{N}_4$  and under  $\neg$ SSGB it is equal to  $Y \neq \mathbf{N}_4$ . Since SSGB  $\Rightarrow$   $M_1 = M$  and  $\neg$ SSGB  $\Rightarrow$   $M_2 = M$  by definition,

**(4.1)** we have a proof of ( SSGB  $\Rightarrow$   $M_1 = \mathbf{N}_4$  )

$\wedge$

**(4.2)** we have a proof of (  $\neg$ SSGB  $\Rightarrow$   $M_2 = Y \neq \mathbf{N}_4$  ).

Then, ( (3.1')  $\vee$  (3.2') ) together with ( (4.1)  $\wedge$  (4.2) ) implies

**(5.1)** we have a proof of (  $\neg$ SSGB  $\Rightarrow$   $M_2 = \mathbf{N}_4$  )

$\vee$

**(5.2)** we have a proof of ( SSGB  $\Rightarrow$   $M_1 = Y \neq \mathbf{N}_4$  ).

Because of  $( (4.1) \wedge (4.2) )$  and because

we have a proof of  $( SSGB \Rightarrow M_2 = \{ \} \neq \mathbb{N}_4 )$

and

we have a proof of  $( \neg SSGB \Rightarrow M_1 = \{ \} \neq Y )$ ,

we have a proof that  $( M_2 = \mathbb{N}_4 )$  is false and we have a proof that  $( M_1 = Y \neq \mathbb{N}_4 )$  is false.

Therefore,  $( (5.1) \vee (5.2) )$  yields

**(6.1)** we have a proof of  $SSGB$

$\vee$

**(6.2)** we have a proof of  $\neg SSGB$ .

Since we have neither a proof of  $SSGB$  nor of  $\neg SSGB$ , both (6.1) and (6.2) are false.

So, we obtain  $( FALSE \vee FALSE )$  and thus  $FALSE$ .

Hence, the assumption that  $PA$  is consistent was false.

□